INTRODUCTION

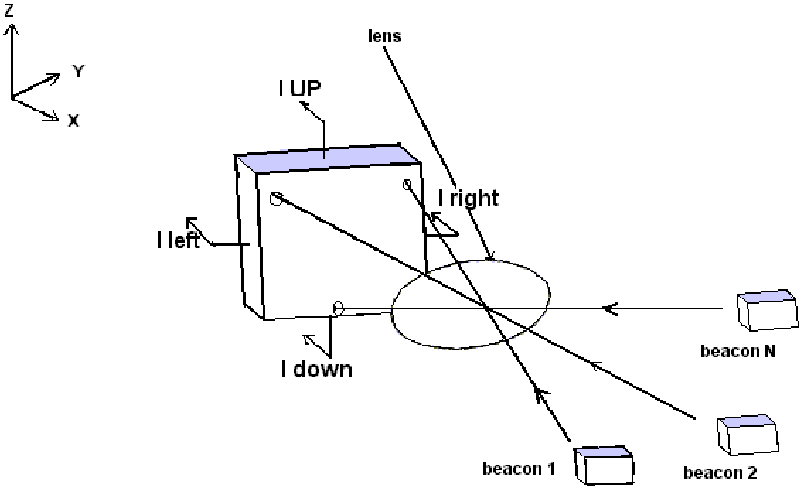
Now days there are several navigation systems for positioning the objects. Several research efforts have been carried out in the field of Six Degrees Of Freedom estimation for rendezvous and proximity operations. One such navigation system used in the field of Six Degrees Of Freedom position and attitude estimation is the VISion based NAVigation system. It is aimed at achieving better accuracies in Six Degrees Of Freedom estimation using a more simpler and robust approach.

The VISNAV system uses a Position Sensitive Diode (PSD) sensor for 6 DOF estimation. Output current from the PSD sensor determines the azimuth and elevation of the light source with respect to the sensor. By having four or more light source called beacons in the target frame at known positions the six degree of freedom data associated with the sensor is calculated.

The beacon channel separation and demodulation are done on a fixed point digital signal processor (DSP) Texas Instruments TMS320C55x [2] using digital down conversion, synchronous detection and multirate signal processing techniques. The demodulated sensor currents due to each beacon are communicated to a floating point DSP Texas Instruments TMS320VC33 [2] for subsequent navigation solution by the use of colinearity equations.

Among other competitive systems [3] a differential global positioning system (GPS) is limited to midrange accuracies, lower bandwidth, and requires complex infrastructures. The sensor systems based on differential GPS are also limited by geometric dilution of precision, multipath errors, receiver errors, etc.These limitations can be overcome by using the DSP embedded VISNAV system

SENSOR DESCRIPTION



Sensor geometry

We have discussed that Position Sensitive Diodes are used for sensing purpose. The Position Sensitive Diode (PSD) is a single substrate photodiode capable of finding or locating a light beam within defined sensing area. When photons meet the PSD sensor active area electrical currents are generated that flow through its four terminals. The closer the incident light centroid is to a particular terminal, the larger the position of current that flows through that load comparison of these four currents determines the centroid location of the incident light

With regards to the above figure the normalized voltage are as follows

Vy=k (Iright-Ileft) / (Iright+Ileft) 8(1)

Vz=k (Iup-Idown) / (Iup+Idown) 8(2)

Where K is a constant value 1 ohm.

This equation (1) is an indication of the angle the incident light beam makes about the object space X axis. Similarly equation (2) is determined by the angle that the incident light beam makes about the object space Y axis

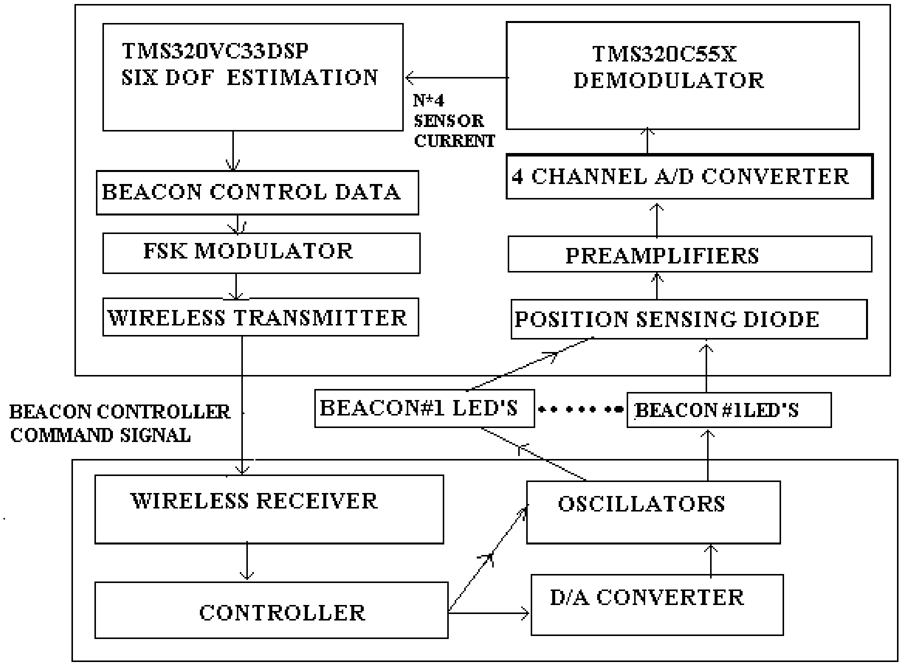
FACTORS AFECTING MEASUREMENT

There is likely to be a large amount of ambient light at short wavelength and low carrier frequencies due to perhaps the sun, its reflections, incandescent or discharge tube lights, LCD and cathode ray tube displays etc. In many cases this ambient energy would swap a relatively small beacon signal and the PSD centroid data would mostly correspond to this unwanted background light.

In order to avoid this problem by modulating the beacon controller current by a sinusoidal carrier of high frequency. The resulting PSD signal currents then vary sinsuoidally at approximately the same frequency and have to be demodulated to recover the actual current proportional to the beacon light centroid. This modulation or demodulation scheme leads high degree of insensitivity to variations in ambient light and it is a key to make the PSD sensing approach practical.

Another method for solving this ambient light problem is that all energy except that centered on the colour wavelength of the beacon is greatly reduced by an optical colour filter. Another problem that affects the measurement is that high power beacon signal may saturate output of the preamplifier which is used after the PSD. So incident light centroid can not measure accurately. In order to avoid this problem a feedback control is used to hold the beacon light intensity at a level that results in a maximum PSD current at approximately 70% of the Tran impedance amplifier input saturation level.

SIGNAL PROCESSING



Block diagram of DSP embedded VISNAV system

This the general block diagram of VISNAV system. A sinusoidal carrier of approximately 40 kHz frequency is applied to modulate each beacon LED drive current. the resulting induced PSD signal current then vary sinusoidally at approximately same frequency and are demodulated to recover the currents that are proportional to the beacon light centroid.

The output of PSD is very weak. So we have to amplify these signals by using a preamplifier. After amplification this signal is fed to four channel analog to digital converter. This converts the four channels of analog data into digital form. And is then fed to the DSP, TMS320C55x [2] to demodulate the signal. After the demodulation the four channel data is fed to the Six Degree Of Freedom estimator, which uses DSP for estimation. From this point we get the sensor co-ordinates. As discussed earlier that the controlling of beacons to avoid the problem of saturation we uses the beacon control data which is given by the DSP, TMS320VC33 [2]. This control data is in digital form. We use radio link to communicate the control data from the sensor electronics module to the beacon controller module.

The beacon control data is then Frequency Shift Key (FSK) modulated. Then it is transmitted by using a wireless transmitter. The wireless receiver receives the control data and the beacon controller controls the amplitude or power level of beacons. This closed loop system estimates the Six Degree Of Freedom of the sensor.

MODULATION AND FREQUENCY DIVISION MULTIPLEXING

The PSDs are relatively fast compared to even high sped cameras, having rise time of about $5\mu s$. this permits light sources to be structured in the frequency domain and utilization of radar-like signal processing methods to discriminate target energy in the presence of highly cluttered ambient optical scenes. If there is a single beacon excited by a sinusoidal oscillator operating at a frequency fc, the emitted light induces sinusoidal currents in the PSD with the frequency fc at the four terminals of the PSD sensor. Therefore, all the four currents can be processed in a similar fashion to estimate the amplitudes of the carrier waveforms. The amplitudes of these currents are related to the azimuth and elevation of the light source with respect to the image co-ordinate frame. If the PSD has a relative motion with respect to the beacon, the current envelopes are modulated by that relative motion and this modulation is analogous to amplitude modulation (AM). Thus the currents can be written as follows,

$$I_k(t) = (A_k.\mathrm{Cos}(2\ .pi\ .f_c\ .t).(1+m_k(t)))+n_k \quad \_\_\_\_\_\_\_\_\_\_(3)$$

where k = 1,2,3, and 4 and it corresponds to the terminal number of the PSD, and A_k is the amplitude of the current waveform generated at the k^{th} terminal of the PSD by the beacon that is fixed with respect to the PSD sensor. The function $m_k(t)$ denotes the signal envelope variation induced by the relative movement of the sensor. This is the case of single beacon operated at single frequency.

If there are multiple beacons operating at different frequencies, then the PSD terminal currents consists of current components at those frequencies, and can be written as follows,

$$I_k(t) = \sum_{j=1}^{N} (A_{j,k} Cos(2 .pi f_j .t).(1 + m_k(t))) + n_{k,} \_\_\_\_\_\_ (4)$$

Where N is the number of beacons and it should be greater than four for solving the 6 DOF inverse problem, $A_{j,k}$ is the peak amplitude of the current generator at the k^{th} terminal of the PSD corresponding to a light beam from j^{th} beacon driven by a sinusoidal oscillator of frequency fj while the beacon is fixed with respect to the PSD sensor, $m_{j,k}(t)$ is the signal due to the relative movement of the sensor with respect to the jth beacon, and $n_{j,k}$ is the noise component due to the jth beacon at the k^{th} terminal.

It is required to demodulate the above composite currents in real time for N*4 channels. The components to be recovered can thus be modeled as

$$r_{j,k}(t)=A_{j,k}(1+m_{j,k}(t)),j=1,2,3,........,N; k=1,2,.......,4 \_\_\_(5)$$

It is worth pointing out that in normalized voltages, which are proportional to azimuth and elevation of the jth beacon with respect to the image co-ordinate frame, are obtained from the following relation similar to equation(1).

$$V_{yj} = k ((r_{j,1}-r_{j,2}) / (r_{j,1}+r_{j,2}))\_\_\_\_\_\_\_\_\_(6)$$

$$V_{z,j} = k\left((r_{j,3}-r_{j,4}) / (r_{j,3}+r_{j,4})\right) \qquad (7)$$

The selection of frequencies for the beacons is based on several factors. The beacon frequency should ideally be above 20 kHz in order to distinguish it from lower frequency background ambient light that might include extraneous lighting sources. If the beacon frequency is too high, the PSD/pre amplifier noise will be greater. For practical purposes, the beacon frequency is selected to be near 40kHz. The separation between the beacon frequencies depends on the bandwidth of the beacon signal.

DEMODULATION

Considering that it is needed to determine the amplitude of the sinusoidal signal and the associated signal due to the relative movement of the sensor, an approach similar to AM demodulation is used here. The main difference, however, is that we are also interested in the carrier amplitude. Although analog circuits can be used to perform the channel separation and demodulation, the DSP based approach provides a more cost effective solution with a higher degree of reliability, programmability and scalability.

In the foregoing discussion, it is shown that for real implementation on a DSP processor, straight envelope detection is not feasible and the use of multirate signal processing can overcome this limitation. The PSD sensor generates four currents and a four channel synchronous analog to digital converter (ADC) samples these four currents. Each current contains the frequency components from around 48.25 to 52.25 kHz.

The sampling frequency of ADC is chosen as to be 210 kHz, which is four times the anticipated maximum frequency component of nearest or 52.5 kHz. Four pre amplifiers with unity gain in the range of 48.25 kHz to 52.25 kHz together with a gradual attenuation at other frequencies are used to supply the currents to the ADC. This attenuation reaches 80dB at higher frequencies around 105 kHz and also at lower frequencies near 0 Hz. The word length is chosen to be 12 bits.

Since all the four PSD currents are similar in terms of frequency components, the beacon channel separation and demodulation methods are common to all of them. Bandpass filtering for the selection of the beacon channel and then envelope detection consisting of rectification and lowpass filtering are performed. Since the beacon carrier frequencies are separated by 500 Hz, the bandpass filter is designed to have a unity gain passband from f_j-100 to f_j+100 Hz, a transition bandwidth of 150 Hz from f_j-250 to f_j-100 and from f_j+100 to f_j+250. The stopband attenuation is around 80dB. The demodulation can be done by implementing algorithms on DSP.

DSP IMPLIMENTATION

The beacons are multiplexed in FDM mode. A low power fixed point DSP, TMS320C55x [2] is utilized for the algorithm of beacon separation and demodulation. Asynchronous analog to digital converter samples the sensor's four currents to feed estimates to the TMS320C55x [2]. Each current has frequency components corresponding to the frequencies of different beacons. For the case of eight beacons the carrier frequencies are starting from 48.5 kHz with an interchannel separation of 0.5 kHz, in order to distinguish from low frequency background noise.

TMS320C55x communicates the demodulated beacon currents to the TMS320VC33 for subsequent navigation solution. The TMS320VC33 [2] estimates the Six Degree Of Freedom position and attitude according to the beacon currents. The algorithm for the Six Degree Of Freedom estimation is implemented on this processor. It also provides feedback control signals to the beacon controller.

ADVANTAGES

- It can be easily reprogrammed
- Insensitive to temperature variations and ageing effects
- It is easily scaled up to 16 beacons with slight modifications in the software.
- It has small size.
- It has wide sensor field of view.
- It has no time consuming image processing employed.

DISADVANTAGES

- The signals may be blocked by opaque objects in their paths.

APPLICATIONS

VISNAV system has a wide range of applications. Two of them are as follows

1. Aerial refueling
2. Spacecraft docking

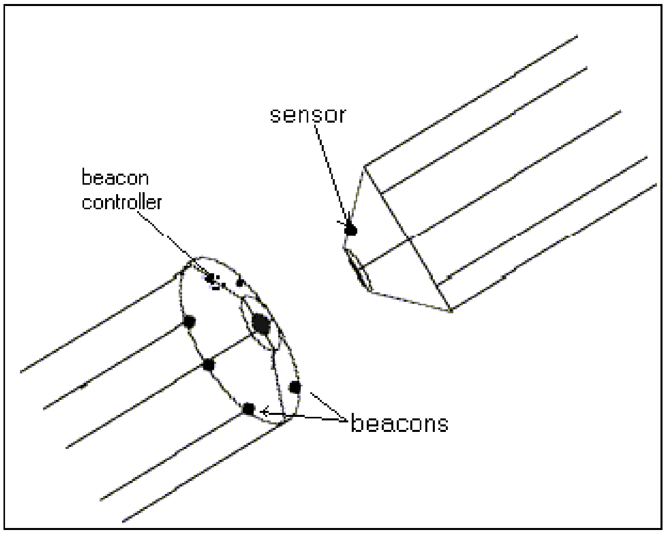
AERIAL REFUELING

The aim this application is to extend the operational envelop of unmanned aerial vehicles by designing an autonomous in flight refueling system. One of the most difficult technical problems in autonomous flight refueling is the accuracy. That is it needs high accurate sensor to measure the location of the tanker and the aircraft. Currently Global Positioning System (GPS) is limited by an accuracy of one foot approximately.

The VISNAV system is capable of providing the needed Six Degree Of Freedom information for real time navigation and can enable accurate autonomous aerial refueling without extensive alterations in the current refueling system.

In order to implement VISNAV system the only thing that is to attach the light sources called beacons on the refueling target frame ‘A’ and an optical sensor called Position Sensitive Diode (PSD) on the aircraft frame ‘B’. The aerial refueling using VISNAV can be used in the 100% of cloud cover, total darkness and adverse weather conditions.

SPACECRAFT DOCKING



Spacecraft docking

This is one of the applications of VISNAV system. In the figure docking point of two spacecraft is shown. The active beacons are placed in one of the docking surface. The beacon controller part is also placed in the same surface. Some beacons are placed near the docking point and some are placed wide apart. This is to provide a wide range of field of view.

The sensor part consists of a PSD sensor which is placed on the other aircraft near the docking point. A beam of light is transmitted from the docking point of the other spacecraft. The sensor senses this light from the spacecraft and is then converted into four currents, whose imbalance is used to find out the centroid of the light. The centroid will give the Six Degree Of Freedom of the spacecraft.

CONCLUSION

A new method for operating beacons and demodulating the beacon currents for the VISNAV sensor system is introduced here. It is shown that target differentiation based on FDM yields higher signal to noise ratios for the sensor measurements and the demodulation in the digital domain using multirate signal processing techniques brings reliability and flexibility to the sensor system. The algorithm that is implemented on DSP is robust when there are four or more of line of sight measurements except near certain geometric conditions that are rarely encountered. It is shown that this algorithm is computationally efficient and achieves better results.

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CONTENTS

ABSTRACT

Spacecraft missions such a spacecraft docking and formation flying requires high-precision relative position and attitude data. Although a global positioning system (GPS) can provide this capability near the earth, deep space missions require the use of alternative technologies. One such technology is the vision-based navigation (VISNAV) sensor system developed at Texas A&M university .J comprises an electro optical sensor combined with light sources or beacons. This patented sensor has an analog detector in the focal plane with a rise time of a few microseconds. Accuracies better than one part in 2000 of the field of view have been obtained .this paper presents a new approach involving simultaneous activation of beacons with frequency division multiplexing as part of the VISNA V sensor system.

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