IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 2, Issue 5, Oct-Nov, 2014
ISSN: 2320 – 8791 (Impact Factor: 1.479)
www.ijreat.org

Odometery And Terrain Mapping Using Optical Sensor Array

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Abstract
An optical system for measuring relative displacement or velocity relative to a surface and the type of surface has been constructed. The signals from the photo detectors / CCD cameras are applied either to a differential amplifier which produces an output signal representing the difference between the photo detector signals or the images captured are cross correlated which thus has a frequency representing the speed or movement of the system relative to the surface. This output signal may then be applied to known frequency counting devices for indicating velocity or distance travelled from a zero position.

Keywords: *Digital image correlation, Optoelectronic sensor, Cross correlation, Optical Mouse, Odometer, Velocity Meter, Tachometer, Vehicle*

1. Introduction

THE optical mouse actually uses a tiny camera to take 1,500 pictures every second. Able to work on almost any surface, the mouse has a small, red light-emitting diode (LED) that bounces light off that surface onto a complementary metal-oxide semiconductor (CMOS) sensor.[8][9] The CMOS sensor sends each image to a digital signal processor (DSP) for analysis. The DSP, operating at 18 MIPS (million instructions per second), is able to detect patterns in the images and see how those patterns have moved since the previous image.[6] Based on the change in patterns over a sequence of images, the DSP estimates how far the mouse has moved and sends the corresponding coordinates to the computer. The computer moves the cursor on the screen based on the coordinates received from the mouse.[11] This happens hundreds of times each second, making the cursor appear to move very smoothly.

This change in pattern when correlated and observed can help in accurately calculating the speed and relative direction of the object it is placed on. We use a series of such optical sensors in a linear array to determine the differences in the relative direction of motion detected and the amount of differences observed between different images to get a perspective of the surface texture the sensor is on.

2. Previous Work Done

Researchers investigating the use of optical mouse sensors for robotic odometry have identified several sources of error including: height displacement (above the measurement surface), type of surface, angular orientation, lighting conditions along with velocity and acceleration of these sources of error, height displacement is particularly significant resulting in most research performing odometry measurements over smooth indoor surfaces which the sensor can make direct contact with and in several cases whilst still mounted in a mouse body.[7][5] Surfaces with significant discontinuities, such as the gaps between tiles, have been shown to introduce additional errors due to the variation in height displacement. For outdoor robotic odometry it is impractical to have a sensor or lens in direct contact with the ground (rough terrain is far more likely to scratch or displace the lens).[3] Further, outdoor surfaces tend to be less smooth and so have significantly more discontinuities compared to the smoother indoor surfaces.[3] Several researchers showing promising results have fitted new lenses to increase the factory prescribed 7.35mm focal length to something in the order of centimetres, which allows the sensor to be mounted a further distance from the measurement surface enabling outdoor odometry. One positive development shown was that as the focal length of the sensors is increased, they become less sensitive to their height displacement over ground, a positive finding which lends these sensors well to outdoor robotic odometery [4]

3. Procedure

3.1 Optical Sensor

More than one thousand successive images per second can be captured by optical mice. The offset between the previous and the succeeding image can vary from a fraction of a pixel to as many as several pixels. This depends on the speed with which is the mice is moving. Cross correlation is used to compute how much each succeeding image is offset from the past one.

An optical mouse might deploy an image sensor having an 18 × 18 pixel array of monochromatic pixels[7] The same ASIC may be used by the sensor as that used for storing and processing the images. Various methods can be used to enhance the process of correlation. To hasten the process of correlation, data from previous motions could be used. Another method that can be employed to refine the process is avoiding the dead bands when moving steadily by adding frame skipping or interpolation.

This can be compared to two photographs of the identical entity except to some extent offset from one another. When both the photographs are placed on a well lit table to make them transparent, slide one across the other until their images line up.[13] The degree to which the edges of one photograph overhang the other corresponds to the offset between the images, and in the case of a vehicle it represents the distance it has moved.[14]

3.2 Two dimensional matrix alignment of optical sensors

The optical sensors are aligned in a 2 D array. Now during terrain mapping these sensors start picking up relative values according to the image correlation done. These values are saved to two 2 dimensional matrices instantaneously.
Let's consider an example array of 9 optical sensors.

$$Sensor's\ X\ Values = \begin{vmatrix} x1 & x2 & x3 \\ x4 & x5 & x6 \\ x7 & x8 & x9 \end{vmatrix}$$

$$Sensor's\ Y\ Values = \begin{vmatrix} y1 & y2 & y3 \\ y4 & y5 & y6 \\ y7 & y8 & y9 \end{vmatrix}$$

3.3 Arithmetic Computation

The mean value of these individual matrices is calculated for further computation. Now this mean thus calculated is subtracted from individual elements of the matrix to calculate the individual instantaneous deviation of each elements of the matrix.

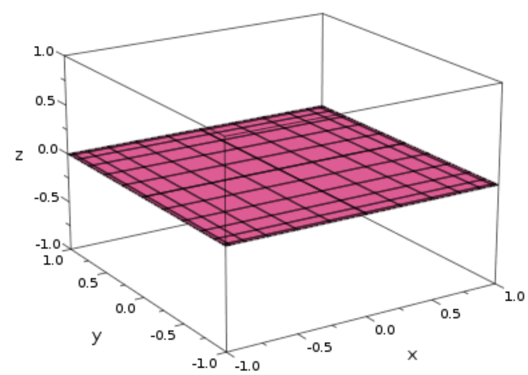
$$Mean\ of\ all\ X = \frac{\sum_1^n x_n}{n} = X_x$$

$$Mean\ of\ all\ Y = \frac{\sum_1^n y_n}{n} = Y_y$$

$$Deviation\ matrix\ \delta_x = \begin{vmatrix} X_x & X_x & X_x \\ X_x & X_x & X_x \\ X_x & X_x & X_x \end{vmatrix} - \begin{vmatrix} x1 & x2 & x3 \\ x4 & x5 & x6 \\ x7 & x8 & x9 \end{vmatrix}$$

$$Deviation\ matrix\ \delta_y = \begin{vmatrix} Y_y & Y_y & Y_y \\ Y_y & Y_y & Y_y \\ Y_y & Y_y & Y_y \end{vmatrix} - \begin{vmatrix} y1 & y2 & y3 \\ y4 & y5 & y6 \\ y7 & y8 & y9 \end{vmatrix}$$

Now these deviation matrices are plotted in form of a plane to analyze the input data. This is done by plotting the individual deviation captured at different (x, y) positions on the z axis.
These points thus obtained are joined together to form a map to determine the texture of the surface recorded. This surface can be classified as rough, smooth, inclined based on the change in the deviation values relatively.



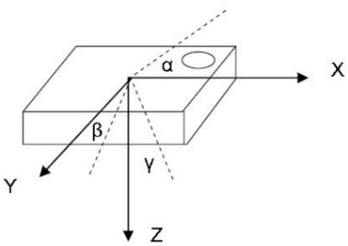
Now a plot of surface is obtained that helps us determine the available type of terrain in consideration.

3.4 Processing

A typical mouse uses MCS-12085 optical sensor which can be used to give an output as a binary 8 bit data from its SCLK and SDIO pins.[1]
To do this we hack open the optical mouse and connect out wires to the sensor pins directly. [2] The sensor then powered up gives the output as a series of on off states as an 8 bit data stream for dx and dy.
Now this data is given to a microcontroller for calculation of the speed and direction from the relative change of values received from the sensor

$$Ax = \arctan\left(\frac{X}{\sqrt{Y^2+Z^2}}\right)$$

$$Ay = \arctan\left(\frac{Y}{\sqrt{X^2+Z^2}}\right)$$



Where Ax = α & Ay = β

4. Conclusion

The project employed optical mice to estimate the type of terrain by using an array of optical sensors to gather data. The process of correlation can be used to determine the type of terrain by using simple matrix calculation. The results from this give close to accurate results. By using more sophisticated sensors and cameras, the project can be upgraded to calculate the depth of the holes in the terrain.

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