Earth Horizon Sensor

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Introduction

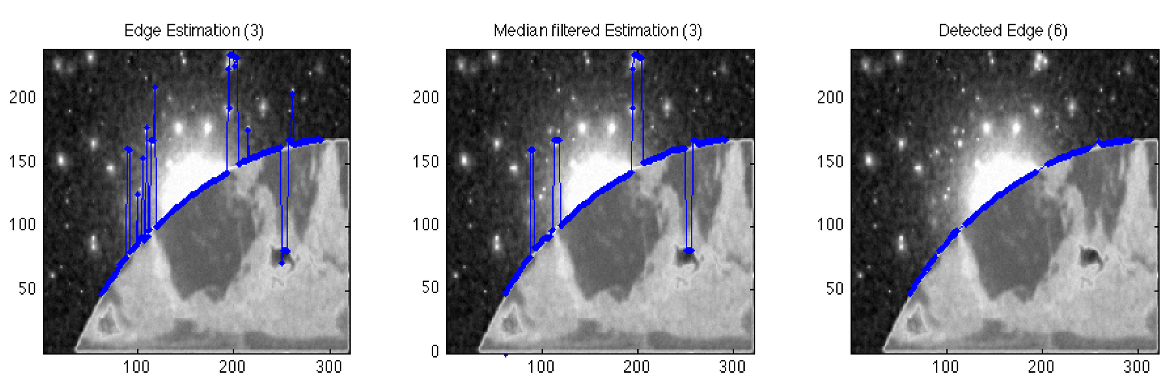
Small spacecraft, like those being developed at the University of Michigan, need a way to determine their attitude (pointing direction) during flight. The purpose of the Earth Horizon Sensor is to determine attitude using an image of the Earth's horizon. Our modular algorithm can be used with standard cameras that already exist on many spacecraft, as well as specialized optical hardware to allow operation when the Earth can not be seen with visible light.

Edge Detection

The edge detection process analyzes the image and determines the orientation and location of the edge.

Process:

1. Determine the orientation of the edge.
2. Determine the boundaries of the edge estimation.
3. Estimate the row or column values of the earth edge pixels.
4. Remove spikes in estimation relative to the neighbor edge point.
5. Apply a "Sobel" filter to the image to compute gradient.
6. Find max gradient pixel within estimated region of edge.



Algorithm Overview

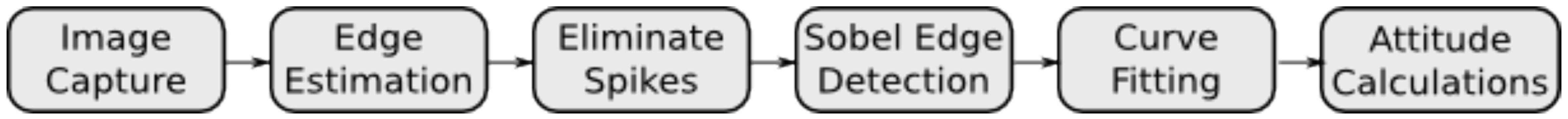


Image Capture: Data processing hardware reads the values of each pixel from the pixel array and stores them in memory.

Edge Estimation: An algorithm scans the entire image to determine the approximate location of the Earth-to-space transition (the horizon). It does this by looking for areas where the intensity of the image abruptly changes from low (space) to high (Earth). Unfortunately, stars, planets, the sun, the moon, and landmasses can produce erroneous horizon detection points, which manifest themselves as spikes in the estimated horizon.

Eliminate Spikes: A median filter and sophisticated algorithm are applied to the estimated horizon to remove these spikes, leaving an estimated horizon only near locations of the true horizon.

Sobel Edge Detection: A precise form of edge detection is then applied to only the regions of the image that were estimated to contain a valid representation of the horizon. The output of this step is a set of points that lie very close to the exact Earth-to-space transition.

Curve Fitting: From the horizon points obtained using edge detection, an iterative algebraic curve fitting algorithm (the Taubin Hyperbola Fit) is applied to determine the equation of the horizon curve.

Attitude Determination: Finally, the equation of the curve representing the Earth's horizon is used to solve for the attitude of the Earth Horizon Sensor.

Curve Fitting

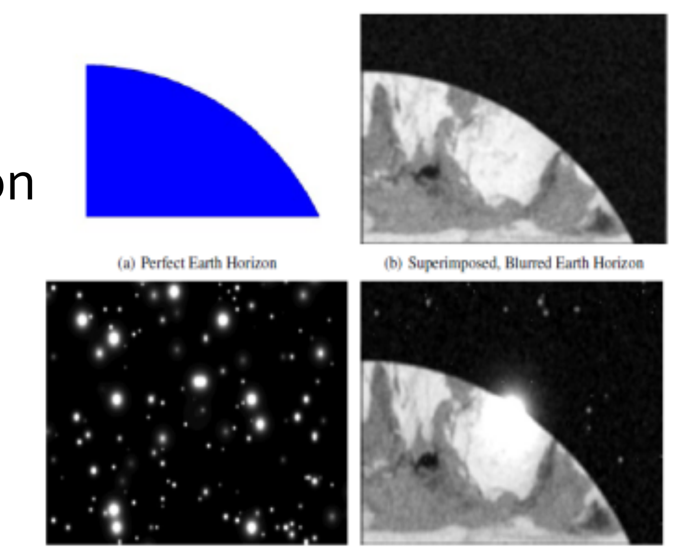
The curve fitting process uses a Taubin Fit algorithm to fit the calculated edge to a hyperbola. Because of the operational altitude of the EHS and the focal length of the camera , the curve will be hyperbolic in nature. The following equation describes the horizon:

$$Ax^2+Bxy+Cy^2+Dx+Ey+F=0$$

Test Cases

The purpose of the test cases is to characterize the performance of the EHS system by providing realistic inputs and expected outputs from the EHS. We have designed different test cases to verify our system's functionality despite a plethora of random variables:

- Sun
- Stars
- Moon
- Spatial Location
- Orientation
- Landforms
- Lighting
- Weather



(a) Perfect Earth Horizon (b) Superimposed, Blurred Earth Horizon (c) Simulation of Stars (d) Final Earth Horizon Image

Attitude Calculation

The Earth Horizon Sensor (EHS) outputs attitude as a unit vector to the center of the Earth, in the coordinate system of the EHS. This vector is computed using roll and pitch angles, which are derived from known camera parameters and the equation of the Earth horizon.