Additional Topics on Environmental Feature Matching

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This appendix comprises additional topics on environmental feature matching, building on Chapter 13. Section H.1 describes Continuous Visual Navigation, an example of image matching, while Section H.2 discusses the suitability of alternative environmental features, comprising road texture, smells and particulates, ambient sound, microclimate, background radiation, and sferics.

H.1 Continuous Visual Navigation

Continuous Visual Navigation (CVN) is an airborne navigation system that uses a downward-looking camera [1, 2]. It was designed to overcome the limitations of scene matching by area correlation (SMAC) in the 1990s. In SMAC, the boundary features were extracted from images to produce binary images that were matched with stored images using correlation (see Section 13.3.2). One correlation method varied the latitude and longitude offsets between the two images, counting the number of boundary pixels that matched, allowing a certain leeway for noise. The offset with the most matching pixels provided the position fix.

SMAC systems were not able to store a complete database of features within the host vehicles's area of operation. Instead, a series of landmark images were stored, from which unambiguous position fixes could be made. However, it was then necessary to pre-plan the host-vehicle trajectory in order to overfly the landmarks, limiting the range of applications for which SMAC was suited.

CVN provides continuous position fixing without the need for prior route planning. This requires the database to cover the whole region of operation. To reduce the amount of storage required for a given area of terrain, CVN matches only straight-line features. Examples include roads, rail tracks, buildings, and field boundaries.

A directly downward-looking camera is used as the images are easier to process than those from camera with a view slanting forward or sideways. This is because a constant scaling may be assumed for the whole image and there is very little shadowing of features by the terrain. However, downward-looking cameras tend to cover a smaller area of terrain, providing fewer features to match with the database.

A radalt is used to determine the height of the camera above terrain, enabling the camera image to be scaled to match the line-feature database. The camera's orientation is determined from an INS attitude solution, enabling the image to be rotated to align its axes with those of the database. The INS is integrated with CVN and any other available sensors, enabling its attitude solution to be continually corrected. Conversely, the INS bridges gaps in the CVN navigation solution when no usable line features are available.

CVN first processes the scaled and rotated images to extract boundaries. Each image line feature is then compared with those lines in the database that are of a similar direction and within the region bounded by about the 3σ uncertainty of the host-vehicle position solution. The offset between the image and database lines then provides a measurement of the position error in the perpendicular horizontal direction to the lines. No attempt is made to match the start or finish points of the line features.

To obtain a position fix from a single image, orthogonal line features are needed. To enable images with single or parallel line features to contribute to the navigation solution, making maximum use of the available data, CVN uses a Kalman filter to estimate the errors in the host-vehicle navigation solution. With the host-vehicle velocity solution providing the distance traveled between images, line-fix measurements from different images may be combined to produce a position fix as described in Section 16.3.4.

A single database line may often be matchable with multiple image lines or vice versa, leading to ambiguous fixes. Any feature matching system produces the occasional wrong fix. In CVN, this is resolved using multiple hypothesis filtering, as described in Sections 3.4.5 and 16.3.5, enabling consistency to be checked across successive fixes.

Where line features are observed in the image but cannot be matched with the database, they are matched between successive images to provide velocity information to constrain the INS error growth.

Over suitable terrain, CVN exhibits a horizontal radial position accuracy of about 10m when integrated with an aviation-grade INS and 20m when integrated with a tactical-grade INS [2].

A version of the CVN algorithms for use with a laser scanner has also been developed, enabling image matching and TRN to be performed using the same sensor [3].

H.2 Alternative Environmental Features

As discussed in Section 13.4, any environmental feature can potentially be used for positioning, provided there is sufficient spatial variation, not too much temporal variation, and the measurement and processing of that feature is practical. This section discusses road texture, smells and particulates, ambient sound, microclimate, and background radiation, all of which could potentially be used for positioning using the pattern-matching method and are explored further in [4]. Positioning using sferics is then discussed.

H.2.1 Road Texture

Different roads have different textures, resulting in different sounds and different patterns of vehicle vibration. Either the texture itself or the transition point from one texture to another could be used for positioning. Roads also have bumps and potholes that could serve as landmarks. Accelerometers and microphones are both practical sensors for these features. Thus, they could be used for positioning if there is sufficient spatial variation. Issues to consider include the effect of rain and snow and that the observability of potholes and some bumps depends on the exact path of the vehicle.

H.2.2 Smells and Particulates

Restaurants, cafés, factories, and farms all produce characteristic smells and other particulates, which could be used to identify their locations. The places where these smells and particulates will be observed will depend on the wind direction, which may or may not be known. There will also be temporal variations. However, as only certain scents and particulates are associated with certain places, their presence can be used to confirm a position hypothesis even where absence cannot be used to eliminate a position. A mass spectrometer can detect a wide range of chemical particulates, but is too large and expensive for most navigation applications. Sensors for detecting individual particulates are small and inexpensive, so sensors for different substances could be combined into an array.

H.2.3 Ambient Sound

Different places produce different sounds, which could potentially be used to identify them. Sound is also easy to measure. However, like smells, sounds vary with time and their propagation is affected by the wind. There are also many sounds that can be heard in many different places and, for vehicle applications, the environmental sound must be distinguished from that produced by the host vehicle and any other nearby vehicles.

H.2.4 Microclimate

Temperature, light intensity, and wind speed can all vary significantly over distances of order 10m, particularly near buildings. They are also easy to measure. However, they also vary with the time of day and the weather. The main challenge in using them for positioning is thus to make reliable predictions against which the measurements may be compared.

H.2.5 Background Radiation

The background level of radiation, due to both natural and man-made sources, varies with location. Digital Geiger counters for measuring variation cost around $250 or €200 and are portable. Thus, in principle, radiation levels could be used for positioning. However, the precision is likely to be poor, both because the variation in radiation level with location is gradual and because the update rate of a Geiger counter is low, particularly if a high precision is required.

H.2.6 Sferics

Sferics are the radio signals produced by lightning strikes, effectively natural signals of opportunity [5]. They are found within and below the very low frequency (VLF) region of the spectrum, occupying frequencies below 30 kHz. The low wavelengths enable them to propagate further into buildings, underground, and underwater than most radio signals. The time and location of each sferic signal's origin are unknown, so must be determined using a network of time-synchronized reference stations at known locations. Positioning is by differential ranging, using multiple signals. Widely-spaced reference stations are required to determine the exact signal origin. However, if the reference stations and user are all close together, while the sferic origin is distant, a common line-of-sight may be assumed, so only the direction of the signal need be determined by the reference network.

References

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