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ROBUST CURVATURE VECTORS CALCULATION FROM RANGE DATA USING ISL METHOD

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ABSTRACT

A new robust method for calculating curvature vectors from range data is proposed. A new scheme ISL (iso slant loop) is introduced for this method. An ISL is defined for each target data point as each of its components has a normal vector which has a constant angle against the normal vector of the target. Usually, the loop has an ellipse-like shape of which the primary and secondary axis match the curvature vectors.

We applied our method to a synthesized data (ellipsoids) with synthesized random noise. The calculated vectors are compared with theoretical curvature vectors. One of other traditional methods (quadric patch) is also tested to the same data and the results are reported. These experimental results show that our method is robust with noisy data.

INTRODUCTION

Representation of three-dimensional objects is one of the most important research issues in computer vision. Since, in general, range images are usually very large in size, one has to find a method to reduce this information in a more organized and compressed manner.

The representation also needs to be viewpoint independent, otherwise one cannot find the pose of objects at the time of measurement.

Much research has been done on polyhedric or parametric surfaces[1,2]. This is essentially, a problem of estimating parameters of known equations from the range data. In reality, however, many objects in the world are composed of free formed surfaces and cannot be easily represented by such approaches.

Some research has also been done on representing free formed surfaces. The method using meta-balls[3] can represent complex free formed surfaces by combination of simple functions. It has problems in regard to the type of objects and the uniqueness of its representation.

Other methods decompose the surface into patches. One can use functions such as B-spline[4], blending[4] or nurbs to connect adjacent patches smoothly after decomposition. Decomposition of a surface needs to be viewpoint independent to make the representation of the whole surface viewpoint independent.

Curvature vectors are known as features which are viewpoint independent. Unfortunately, these vectors are also known to be very sensitive to noise[5]; it is difficult to obtain reasonable results from real data. Hence, some research which has used curvature values for segmentation has calculated them on only "finely smoothed" range data[4,6,7].

In this paper, we propose a new method to stably calculate curvature vectors on a C_2 continuous surface. We first describe the new method proposed for calculat-

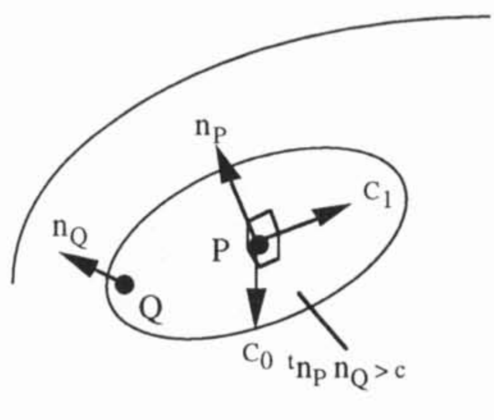

Fig.1 Iso-Slant-Loop(ISL)

ing curvature vectors, show the results of experiments and analyze the result.

CURVATURE VECTORS

Fig. 1 illustrates the basic concept of iso-slant-loop (ISL). Let us suppose that the three-dimensional range data points of a smooth surface are mapped on a 2-D space(U,V) densely, for example, by a range finder[8]. First the normal vector for each point is calculated. Then, for each point P on the surface, one can define a set of points {Q} which satisfy the following relation:

$${}^{t}n_p \, n_q > c \quad (0 < c < 1) \qquad (1),$$

where n_p and n_q are normalized normal vectors of P and Q respectively, and c is a constant.

We define the boundary of {Q} as an ISL of P. As P is always included in {Q}, one can always define a single closed boundary for ISL as follows. First, start from P to find the first point of the boundary. Then, track the boundary using formula (1).

Although the size of an ISL varies with constant c, the shape is generally long in the direction where curvature is minimum and short in the direction where maximum. First, the ISL points are plotted onto the tangent plane of P along the perpendicular line. Then, the curvature vectors are calculated as eigenvectors for the ISL points.

The value c is determined dynamically in the following experiments by finding the largest ISL which has points in the neighbour of P.

When one finds the first point of the boundary in real data, it can be on wrong loops caused by noise, which are boundaries of small regions with irregular normal vectors. One can ignore them by monitoring clockwise and counterclockwise turns on the trajectory.

There are two cases when P is not given curvature vectors. One case is when P is a special point (as a point on a sphere, the singular point on a saddle surface, etc.) and the ISL can be almost a circle. In such case, P is labeled as "curvature vector undefined". The other case is when the minimum value of the inner products between n_p and any normal vector in the neighbour of P is large, i.e. almost 1.0. In such case, P is labeled as "flat surface".

EXPERIMENTS

The range data used in the experiments is a synthesized ellipsoid of 20 cm x 10 cm x 10 cm diameter located at 1 m distance of camera. Three data sets are provided with different scales of white noises, where standard deviations of error are 0, 0.5 mm and 1.0 mm. The map size is 256 x 256. As the object is a body of revolution, the "true" principle curvature vectors are orthogonal to the rotating axis.

Three methods were tested for calculating curvature vector maps: (1) ISL: using eigenvectors of ISL, (2) QUADRIC: fitting quadric function onto the neighbour of P and (3) HYBRID: fitting quadric function onto the ISL points.

The curvature vector maps are compared with the true curvature vector map which is theoretically obtained from the surface equation[9].

Fig.2 is the results of curvature vector maps using three methods for three range data sets. In these figures only principle curvature vectors are shown by needles. Only the method using eigenvectors of ISL is robust against the noise on range data.

Fig.3 shows the result more quantitatively. These graphs are cumulative number along the difference angle between the curvature vector calculated with each method and the true vector for each point. By QUADRIC and HYBRID method, a large number of points have large errors when the range data has small noises, and by ISL method the increase of errors is very small.

DISCUSSIONS

The results shown in Fig.2 and Fig. 3 indicate that the calculation method using eigenvectors of ISL is the most robust among the three methods. QUADRIC is the worst and HYBRID is in the middle of them. In Fig.3, the difference among curves for three different noise levels shows that most of the curvature vectors using ISL method have small errors even with noisy range data, when errors using other methods get worse as noise increases.

The basic difference between traditional methods and our method is in the selection of points to calculate curvature vectors. In traditional methods, curvature or curvature vectors are calculated on points inside a local fixed window around the target point. Otherwise, we

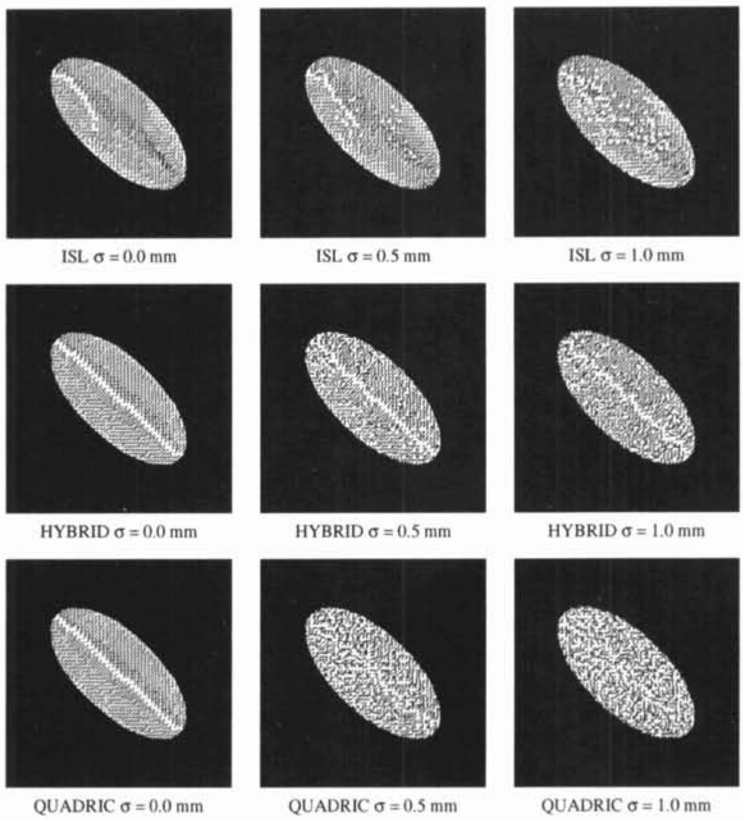

Fig.2 Curvature Vector Map (Principle Vector)

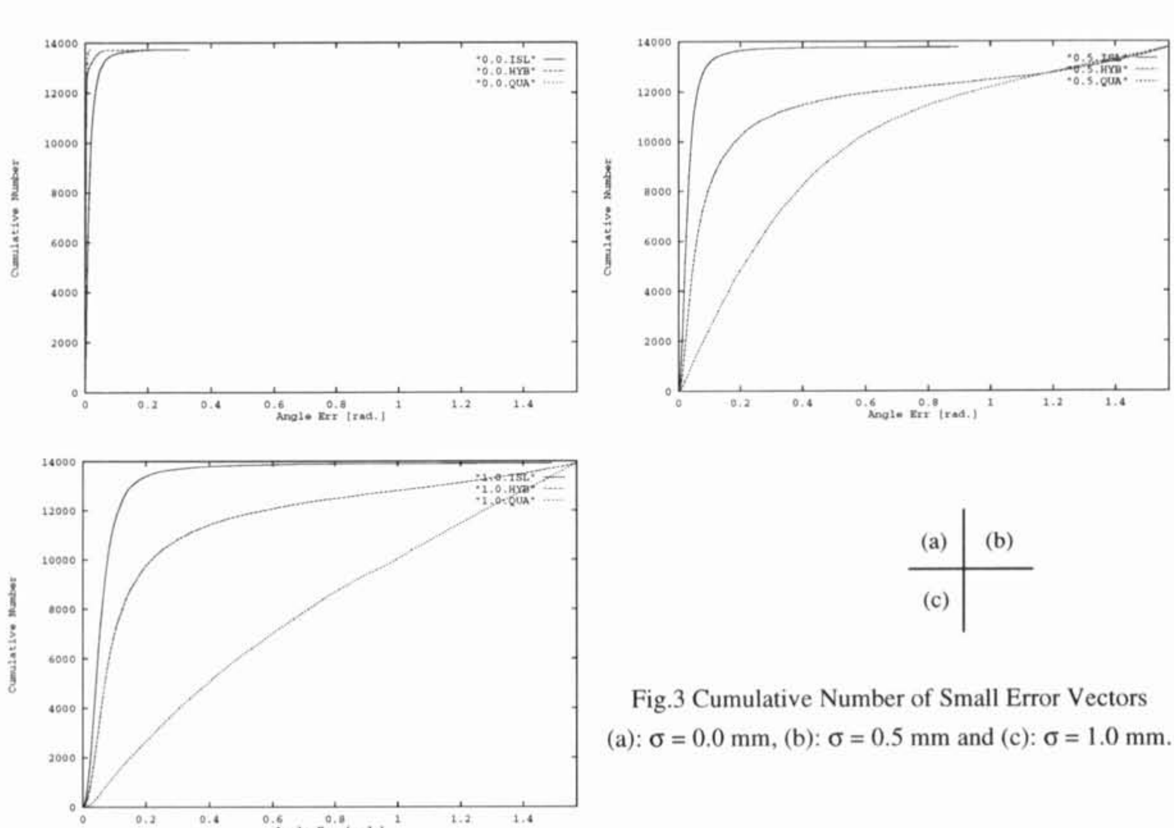

Fig.3 Cumulative Number of Small Error Vectors
(a): $\sigma = 0.0$ mm, (b): $\sigma = 0.5$ mm and (c): $\sigma = 1.0$ mm.

use the primary direction of ISL which dynamically changes the shape according to the surface property itself. The fact that HYBRID results better than QUADRIC shows that the selection of points using ISL is better than points using a fixed window.

In the traditional methods, curvature values or curvature vectors are calculated by differentials of normal vectors. Since they are division between two small numbers, difference between close normal vectors and distance of close points, those methods are sensitive to noise. In this method, no division is necessary on calculation, because one does not need curvature values but instead needs curvature vectors.

The constant c in formula (1) is changeable according to the noise level or curvature values of the surface. When the range data is noisy, c has to be a small value otherwise the noise may split the ISL into pieces. When the maximum curvature value is small, c has to be a large value otherwise ISL becomes large and it is affected by far points and cannot reflect the local feature any more. In our program, the constant c is dynamically changed depending on the roughly estimated maximum curvature value of the target point so that the nearest point of ISL does not go far from the target.

In special case, when the Gaussian curvature of P is 0, an ISL may have a large size along the ridge and the longest direction of the ISL is no longer equivalent with the minimum curvature vector, because it is affected by the shape of distant surfaces. Even in such case, the nearest part of the ISL is reliable and one can use the average of tangent vectors for nearest points of ISL as the minimum curvature vector. In this way, the ISL can be localized and makes it free from shape of the influence of distant surfaces.

CONCLUSION

In this paper, we proposed a new concept ISL and a method using ISL to obtain curvature vectors, which is more robust than traditional methods. The validity of the method is proved with experimental results.

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