LOCAL QUATERNION WEIGHTED DIFFERENCE FUNCTIONS FOR ORIENTATION CALIBRATION ON ELECTROMAGNETIC TRACKERS.

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ABSTRACT

The accuracy of the electromagnetic tracking systems has been always an important issue with application to motion and kinematic analysis [1, 2, 3, 4, 5]. Applications in virtual reality and gesture recognition [6] require not only of improved accuracy but also fast error compensation. Several analytic methods have been used in order to correct the position error and they are well known and fast: polynomial fitting [7, 8], calibration tables [8], and more recent, neural networks [9]. We are interested in the orientation calibration of working spaces with possible high distortion conditions. Such conditions are prevalent in virtual environment spaces such as the CAVE and it is not always possible to avoid metallic components in the surroundings.

In this paper, we introduce a calibration method for a multiple-sensor electromagnetic tracking system in an environment with highly electromagnetic distortional conditions. The target system is a twelve-sensor Ultratrak Polhemus Inc.™ system. We compare two possible formulations: global parameter estimation and local parameter estimation for the corrective functions. It is assumed that the inverse quaternion error Q_ϵ^{-1} exists and it is a function of the three-dimensional location:

$$Q_\epsilon^{-1} \rightarrow f(x, y, z).$$

1. INTRODUCTION.

Raab [10] suggested the use of electromagnetic fields as way to measure the position and attitude of an object in a three-dimensional space. The orientation calibration and compensation of any three-dimensional tracking system is not, in general, a trivial task and remains mostly open. All existing approaches are time consuming and make use of other type of mechanical orientation referencing arrangements such as jigsaws [4] or seven degrees of freedom multi-linked positioning arms [11]. As for the compensation method itself, the approaches can be divided into two main classes: orientation matrix correction methods [7, 2, 12] and quaternion-based correction functions [13].

There are several inconveniences in the use of orientation matrix compensation methods. Firstly, the methods are not robust since they are always exposed to orientation singularities, a.k.a. "Gimbal lock." Secondly, the number of calibration orientations required for each point is high (at least twenty four possible combinations for each point). Thirdly, the number of equations to solve increases up to seventy-two linear combinations, so the computational cost is also high. Finally, the approximation depends on a high order polynomial that, in the best of cases, oscillates about the corrected point for an specific spatial location.

The use of quaternion-based correction functions are grounded on either local correction interpolative techniques [13] or global high order quaternion polynomial fit, as initially suggested by Bryson [7]. In most instances, it is rather difficult to find a global low order polynomial fitting function for the quaternion space. More recent approaches prefer a local interpolation solution technique, either linear quaternion interpolation [13] or a trilinear quaternion interpolation [14, 11].

The overall proposed calibration method is similar to the presented in [13] with several key differences:

1. In Kindratenko [13], the weights is a linear function of the distance from the position of the sensor to the vertex of each square block. In our approach the weighting function is similar to a trilinear interpolation scheme but we use a quasi-linear function for each of the parameters of the quaternion function. That is, the weighting is a distance function from the point to the cell vertexes. In our case, each parameter q_i of the quaternion $\boldsymbol{q}(\boldsymbol{p})$ is calculated as weighted contribution of the corresponding quaternion value

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on each vertex of the square box cell:

$$\boldsymbol{q}(\boldsymbol{p}) = \big(q_1(\boldsymbol{p}), \langle q_2(\boldsymbol{p}), q_3(\boldsymbol{p}), q_4(\boldsymbol{p})\rangle\big), \qquad (1)$$

$$q_i = q_i \frac{\sum_{j=1}^{8} w_j(\Delta x_j, \Delta y_j, \Delta z_j)}{\|\boldsymbol{w}(\Delta x_j, \Delta y_j, \Delta z_j)\|} \qquad \forall \quad i \in \{1, 2, 3, 4\}, \qquad (2)$$

i.e., each parameter of the quaternion $\boldsymbol{q}(\boldsymbol{p})$ is a solution from a scalar field.

$$\begin{aligned} w_j(\Delta x_j, \Delta y_j, \Delta z_j) =& a_1 \Delta x_j + a_2 \Delta y_j \ldots \\ &+ a_3 \Delta z_j + a_4 \Delta x_j \Delta y_j \ldots \\ &+ a_5 \Delta x_j \Delta z_j + a_6 \Delta y_j \Delta z_j \ldots \\ &+ a_7 \Delta x_j \Delta y_j \Delta z_j + a_8. \end{aligned} \qquad (3)$$

where $\Delta x, \Delta y, \Delta z$ are the distances from any point $\boldsymbol{p}$ on the corresponding spatial axes inside the cube to each one of the vertexes of the cube, indicated by the subindex $j \in \{1, 2, \ldots, 8\}$. Each coefficient a_i, $i \in \{1, 2, 3, \ldots, 8\}$ is calculated from a fitting function and stored for each local cell. One important advantage of such approach is that the resulting function is C^0-continuous inside the cell block.

2. Kindratenko's weighting function assumes that the calibration space is not highly distorted, therefore is possible to assume a linear simplification such as:

$$w(d_j) = \begin{cases} 1 - \frac{d}{d_{max}} & \text{if } d < d_{max}, \\ 0 & \text{if } d \geq d_{max}. \end{cases} \qquad (4)$$

Another possible variation is:

$$w(d_j) = \begin{cases} 1 - \left(\frac{d}{d_{max}}\right)^2 & \text{if } d < d_{max}, \\ 0 & \text{if } d \geq d_{max}. \end{cases} \qquad (5)$$

Which, reported by Kindratenko [13], has led to better results in the compensation of the static error for the interpolated rotation. This suggests that by introducing minor non-linearities in the weighting function, it is possible to improve the correction factors.

2. METHODS.

Two data sets were acquired for each sensor, one for calibration purposes and the other one for value testing. In both data sets, each position over the grid is sampled 400 times. The resulting averages for position and orientations are taken. The position average is the statistical mean of the measured readings for spatial position while the orientation average is obtained from passing the sensor attitude into the quaternion space for each of the samples. Then, using a "center of mass" calculation based on a previous exponential mapping of the quaternion space [15], where the quaternion average is obtained.

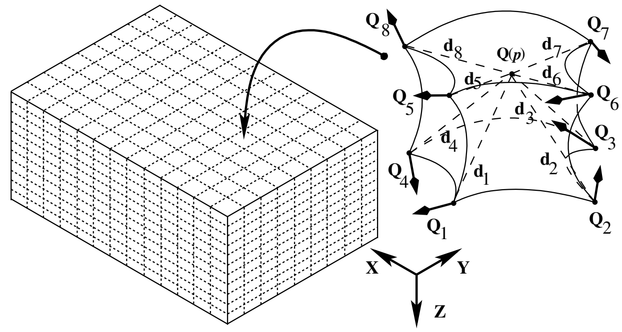

Fig. 1. Measured orientations for a single cell and expressed as quaternions for each corner in the square block.

Initially, the space to be calibrated is divided into a three-dimensional grid with square block cells of 20 cm. × 20 cm. × 10 cm. each for the variables x, y, and z respectively,, as shown in Fig. (1). The testing data set was also measured with the same squared block dimensions but with a position offset of 10 cm. × 10 cm. × 5 cm. so each point of the overlapping data set is positioned at the center of a cell block of the calibration data set. In total, a space of 2.4 m. × 1.6 m. × 1.2 m. was calibrated.

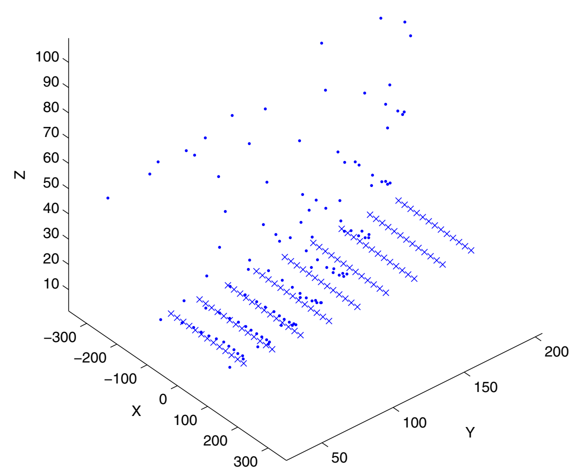

Fig. 2. One layer from the three dimensional measured field points. The field is highly distorted due to the presence of metallic elements in the virtual room. The measured points are compared against true position locations. Scale in cm.

3. RESULTS.

In comparative results, we found that we required a global high order polynomial, 9^{th} order, to fit for the position within the highly distorted field Fig(2). Which led to undesired oscillations of the compensation position. Whereas the local approximation the local interpolation for position yield better results with only the quasi-linear function, Eq. (3). The correction factor based on local interpolation schemes for orientation provides a linear solution for the three dimensional orientation problem, Unfortunately, the calibration sample capture process time is increased due to the altered requirement for a better linear approximation by reducing the size of the sampled cells.

The quaternion measurement indicates a dependency of the three dimensional metric from the transmitter to the sensor. In Fig. (3), it is possible observe the distortion of the field. While the quaternions are highly concentrated in one particular area for which the distance is small to the transmitter, the measurements for quaternions farther from the transmitter tend to be sparse.

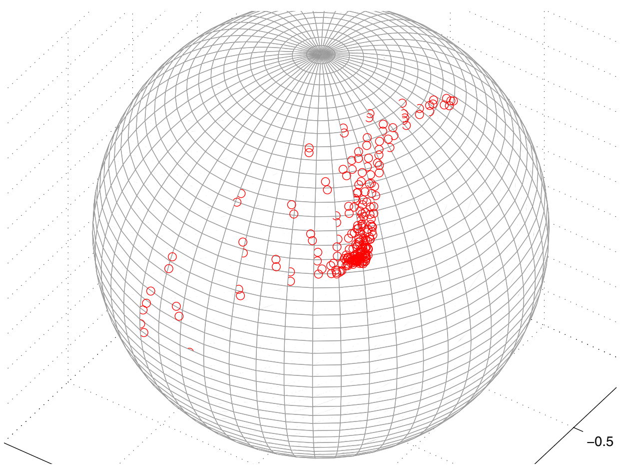

Fig. 3. Unit norm quaternion space sphere. The point distribution on the sphere indicates a three-dimensional rotation value as function of the distance to the transmitter. The observed pairs correspond to the corners on the mesh cubes.

4. CONCLUSIONS.

The implemented method reduces the number of orientation samples for each spatial position, although it increases the number of points in which one has to divide the mesh in order to increase the accuracy of the calibration. The polynomial expressions for local cells are simplified with quasi-linear expressions that are fast to calculate and allow online motion capture.

The method proves to be adequate for less distorted fields, particularly, the areas closer to the transmitter. The high non-linearities in the unit quaternion space are a challenge as the distance from the transmitter increases as observed in Fig. (3).

The orientation distribution in the quaternion space for this application is highly distorted and requires a solution that is local for each voxel of the calibrated space. An inverse quaternion correction of sensor orientation is less accurate when the distance from the transmitter increases. The orientation correction factor is a function of the position from the transmitter as shown in Fig. (3). As for orientations, measurements show that even in highly distorted electromagnetic fields, it is possible to obtain a degree of compensation that is fast and reliable.

5. FUTURE WORK.

We will explore further the mappings between the quaternion space and the three-dimensional position in order to increase the accuracy. Due to the high non-linearity of the mapping between position and orientation, it is necessary to optimize the weighting functions within the particular voxel. A metric of the sphere space may prove more adequate to the optimization for weighting functions in quaternion space.

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