Integrating Gyroscopes into Ubiquitous Tracking Environments

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ABSTRACT

It is widely recognized that inertial sensors, in particular gyroscopes, can improve the latency and accuracy of orientation tracking by fusing the inertial measurements with data from other sensors. In our previous work, we introduced the concepts of spatial relationship graphs and spatial relationship patterns to formally model multi-sensor tracking setups and derive valid applications of well-known algorithms in order to infer new spatial relationships for tracking and calibration.

In this work, we extend our approach by providing additional spatial relationship patterns that transform incremental rotations and add gyroscope alignment and fusion. The usefulness of the resulting tracking configurations is evaluated in two different scenarios with both inside-out and outside-in tracking.

Keywords: Augmented Reality, Tracking, Calibration, Sensor Fusion, Gyroscopes, Inertial Sensors

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.3.1 [Computer Graphics]: Hardware Architecture—Input devices

1 INTRODUCTION

In our previous work, we introduced the concepts of spatial relationship graphs (SRGs) [3] and spatial relationship patterns [4], which allow for formally modeling relationships between the different coordinate frames in a tracking setup and for describing the operations performed by a tracking/calibration algorithm. The goal of this work is to derive new spatial relationship patterns that allow us to integrate gyroscopes into our formal framework and to show that this results in useful sensor fusion configurations.

Related Work Hybrid tracking setups, consisting of inertial sensors combined with other means of tracking, are a well-studied field of research. Azuma [2] has introduced gyroscopes into AR, and the topic has been further investigated by many others. Inertial sensing has also enjoyed some attention in the robotics community.

2 SPATIAL RELATIONSHIP GRAPHS AND PATTERNS

A *Spatial Relationship Graph* (SRG) is a graph which captures the structure of a tracking environment. The nodes of the graph represent the coordinate frames or orientation free points of real or virtual objects, while the directed edges represent the actual information about relationships between these objects.

A *Spatial Relationship Pattern* represents a subgraph template which captures the structural properties of an algorithm for tracking or calibration. Patterns have input (dashed lines) and output (solid lines) edges, that describe the new relationships that can be inferred from given data by a particular algorithm. Starting from an initial SRG with only the pure tracking data, a chain of pattern applications can be used to construct a dataflow network that computes a particular relationship at runtime [4].

3 INCREMENTAL ROTATION

We start the discussion of gyroscope integration by deriving some basic patterns for transforming incremental rotations. Given two sequential rotations r_{t_1} and r_{t_2} at times t_1 and t_2, we can express r_{t_2} by r_{t_1} multiplied by an incremental rotation Δr:

$$r_{t_2} = r_{t_1} \cdot \Delta r \quad \textit{where} \quad \Delta r = r_{t_1}^{-1} \cdot r_{t_2}$$

In the SRG notation, we treat incremental rotations as separate edges, labeled $\Delta\mathsf{Rot}$. Absolute rotation edges are labeled Rot.

The first important transformation of relative orientation is the change of the target coordinate frame. For any given pair of rotations r and q let $r' = r \cdot q$ be the product of r and q which effectively moves the target coordinate frame of the transformation r. As q is static in typical gyroscope scenarios, we can derive

$$\Delta r' = q^{-1} \cdot \Delta r \cdot q.$$

Similarly, if we let $r' = q \cdot r$ we can change the source coordinate frame of the rotation r. In this case we calculate the resulting incremental rotation in the transformed coordinate frame $\Delta r'$, again assuming that q is static, as

$$\Delta r' = \Delta r$$

This means that incremental rotations are valid for all source coordinate frames that are connected by static transformations.

The third transformation of incremental rotation we need is the inversion, i.e. the exchange of source and target coordinate frames. In order to compute $\Delta r'$ of $r' = r^{-1}$, we also need to know the absolute orientation:

$$\Delta r' = r_{t_1} \cdot \Delta r^{-1} \cdot r_{t_1}^{-1}$$

The resulting spatial relationship patterns for transforming incremental rotation are displayed in figures 1 (a)-(c).

4 GYROSCOPE ALIGNMENT

Before the gyroscope can be fused with another tracking system, we need to compute the unknown but static transformation between the gyroscope and the object it is attached to. This is an instance of the so-called “hand-eye calibration” problem [1], for which the robotics community has developed a number of solutions. As only the rotation part needs to be computed, we use the first step of the Tsai-Lenz [6] algorithm, which is based on quaternions and is easy to implement. The spatial relationship pattern of the gyroscope calibration is shown in figure 1 (d).

5 GYROSCOPE FUSION

In order to fuse the incremental gyroscope measurements with those of an absolute tracker we use an extended kalman filter similar to the one described by Azuma [2]. However, we distinguish between the two cases of outside-in and inside-out tracking. While the outside-in case is straightforward, the inside-out fusion filter uses a

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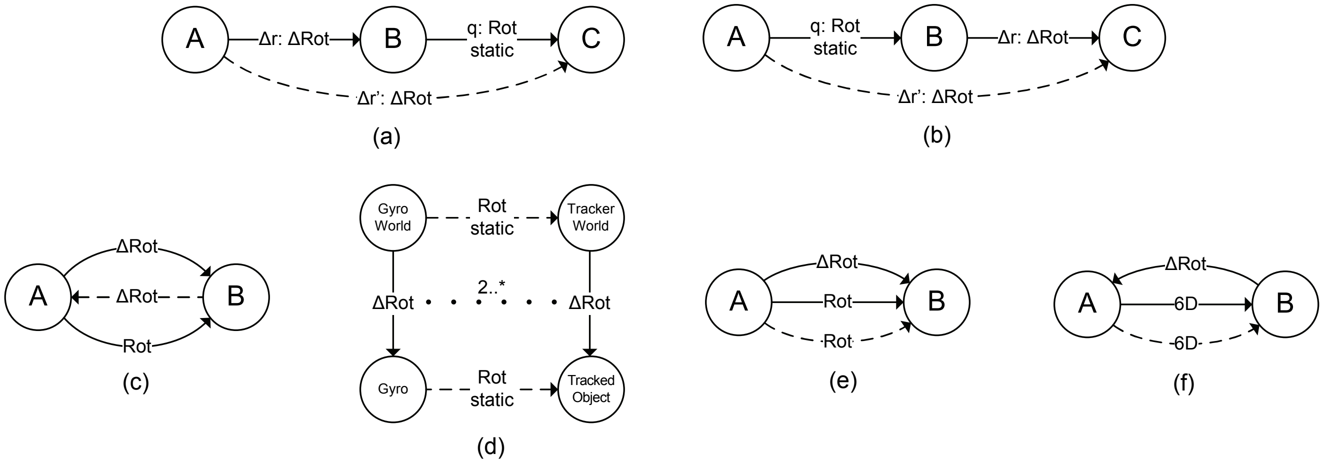

Figure 1: New spatial relationship patterns for dealing with incremental rotations: (a) target coordinate transformation, (b) source coordinate transformation, (c) incremental rotation inversion, (d) gyroscope calibration, (e) outside-in fusion, (f) inside-out fusion

different motion model that explicitly takes into account the fact that rotation of the object also results in a translation of the fixed world coordinate frame as observed by the tracker. The spatial relationship patterns for gyroscope outside-in respectively inside-out fusion are shown in figures 1 (e) and (f). It can be seen that for inside-out tracking, the gyroscope edge is inverted, compared to the absolute tracker.

6 EVALUATION

We evaluated the gyroscope calibration and fusion in two different scenarios. We first attached the gyroscope to a camera that tracked a square marker, similar to the AR-Toolkit. Four different camera motion sequences were recorded and the prediction error was computed, i.e. how well the Kalman filter was able to predict the next measurement of the absolute tracker. Table 1 shows that using the gyroscope improves the prediction in all cases. Furthermore, the inside-out motion model is significantly better in the "still" sequence, where the camera does not move, and is placed directly in front of the marker, resulting in poor orientation estimation.

	outside-in		inside-out	
	w/ gyro	w/o gyro	w/ gyro	w/o gyro
still	22.8	68.0	1.2	1.2
slow rotation	2.6	5.6	3.0	5.2
fast rotation	9.1	94.1	10.8	91.0
full motion	6.5	11.0	7.3	9.3

Table 1: Average prediction error in pixels

In the second evaluation scenario, the gyroscope was attached to a head-mounted laser projector [5], tracked by an A.R.T. infrared outside-in tracker. Figure 2 shows the projected image during a typical head rotation. The registration with the target hole is significantly improved when using the gyroscope (square) compared to using the outside-in tracking alone (triangle).

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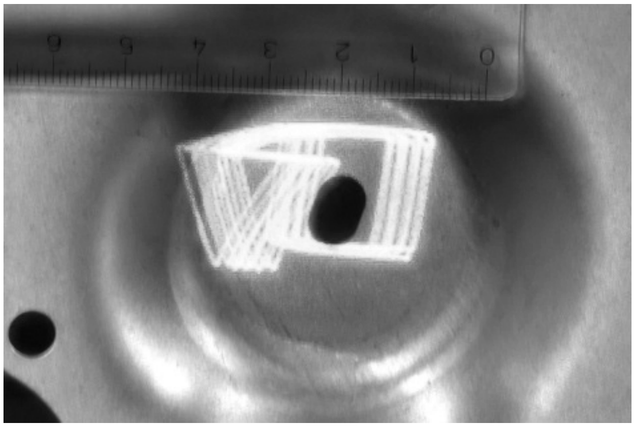

Figure 2: Projection while a sideways rotation is performed

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