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# Attitude-sensor-aided in-process registration of multi-view surface measurement

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ABSTRACT

A novel method for in-process registration of 3D point clouds scanned from different views is presented. A miniature attitude sensor, which can output its pitch, roll and yaw angles in real-time, is mounted on the scanner. The relative pose between the attitude sensor and the scanner is calibrated in advance by a simple yet effective algorithm. When the scanner is moved from one standpoint to another in a measuring process, the real-time readings of the attitude sensor is utilized to compute the rotation movement of the scanner. After applying the rotation transformation to the current point dataset, the translation movement is efficiently determined by exploiting the normal vector constraint between the correspondence points. The rigid transformation obtained fully automatically can serve as a qualified initial estimate for further fine registration. Experiments demonstrate the applicability of the proposed method.



## 1. Introduction

The applications of three-dimensional (3D) shape measurement are widespread in the fields of industrial design and manufacturing, relic restoration, biomedicine and computer vision. There are various non-contact optical instruments involved in 3D surface measurement which are based on time-of-flight lasers [1], laser scanning [2], stereovision [3,4], and structured light [5]. These optical instruments can efficiently capture dense point clouds, which reveal the detail surface shape of the object/scene being scanned. However, all of them can only obtain partial area of the object/scene at one standpoint due to occlusions and the limited field of view of the sensor. In order to build a complete 3D model, it needs to collect point clouds acquired from different views. These multi-view scans are represented in their own local coordinate system, and geometrically aligning them to a global coordinate system is the registration problem.

### *1.1. Related work*

Solutions that are commonly used in practice to registration of scans taken from different views can be classified into three categories:

(1) Using fiducial markers [6,7]. The markers can be planar or solid and are usually adhered on or near the object to be scanned. While the measuring sensor is taking point clouds from a specific view, the 3D coordinates of the markers within the view are obtained at the same time. The relative position and orientation of two scans can be easily determined if only three or more markers are visible in both views. This registration method is usually fast and reliable. However, except for the preparation work before the measurement, the drawbacks of this strategy include that the areas covered by the markers cannot be digitized reliably. This problem is outstanding especially for objects with small size and abundant details. Moreover, adhering markers on the surface is obtrusive or even prohibited in some applications.

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(2) Exploiting mechanical devices like turntables [8] or multi-joint robotic arms [9]. In this solution, either the scanner or the object to be measured is placed on the mechanical device, whose movement can be strictly controlled. The movement parameters of the device are used to compute the geometric transformation between the scans. This solution works well for some applications, yet it is limited for measuring large surfaces or complex objects. The use of extra mechanical devices unavoidably reduces the flexibility and portability of the measuring system.

(3) Employing another set of optical or magnetic devices to trace the scanner. For instance, *leica T-scan*® combines a camera and a laser tracker to monitor the infrared targets fixed on the scanner and thereby determines the position and orientation of the scanner [10]. The optical/magnetic tracing devices can work in a large volume and obtain good registration result. However, the add-on tracing devices are relatively heavy, cumbersome, and sometimes more expensive than the point cloud scanner itself.

Instead of using markers or auxiliary devices, many researchers made efforts to solve the problem by exploiting clues involved in the range images themselves. Without any previous knowledge of the pose of the views, this type of techniques generally follows two basic steps: coarse registration and fine registration.

In coarse registration, an initial estimation of the rigid motion between two sets of 3D points is computed from the correspondences between both surfaces. The most common correspondence used is point-to-point, typically established by analyzing some salient features, such as the Point Signature [11], the Spin Image [12] and the Principle Curvature [13]. According to the correspondences established, most coarse registration algorithms utilize an iterative optimization process to estimate the motion. As pointed out in the comprehensive review paper [14], the iterative coarse registration algorithms, including the ones based on Ransac [15] or genetic algorithm [16,17], require a lot of time to get the motion estimate when the amount of points used in the registration is large (as is the case in practical use). Although there are a few providing fast linear solutions, like the methods based on Principal Component Analysis [18], the result obtained is often very bad since the overlapping region between two practical scans is usually not significant enough for this type of algorithms.

The goal of fine registration is to obtain the most accurate solution as possible. The fine registration methods refine an initial transformation matrix by minimizing the distances between the temporal corresponding points in the datasets. The most representative one is the ICP (Iterative Closest Point) algorithm [19,20] and its variants [21–24]. These algorithms differ from each other mainly in: (a) the way of defining the minimization distance, either point-to-point or point-to-plane; (b) the way to speed up the algorithm; and (c) the way of computing the motion in each iteration. An extensive comparison and experiment-based evaluation on fine registration algorithms can also be found in [14].

In general, the problems concerning fine registration, such as convergence to local minima and high computation cost, greatly depend on a proper initial estimate of the rigid motion. However, as mentioned above, to obtain an acceptable motion estimate is usually quite time-consuming. This limits the practical use of these registration algorithms in real measuring process. This also partially explains why the industrial solutions to in-process registration problem still resort to adhering markers or add-on devices. Therefore, a fast and reliable method to automatically realize the registration in the measuring process is on-demand.

### 1.2. Motivation

Nowadays, a kind of miniature attitude sensor (MAS) has been widely applied in tracking control [25], platform stabilization [26], and ambulatory human movement analysis [27], etc. In these applications the orientations of the carrier, on which the sensor is mounted, can be captured in real-time according to the readings of the attitude sensor.

By using the microelectromechanical (MEMS) techniques, the attitude sensor can now be made very compact in size and light in weight, typically no larger than a matchbox and weighing only several tens of grams. A typical MEMS attitude sensor includes three types of sensing elements: tri-axial gyros, tri-axial accelerometers and tri-axial magnetometer units [28]. The gyros are used to measure the absolute angular rate of the carrier, and then its orientation angles are obtained through special integration of the gyros outputs. The accelerometers are used to determine sensor's tilt and to correct for gyro drift in the pitch and roll angles. The magnetometers are used to perform the initial alignment in azimuth and to correct for gyro drift in the yaw angle. By using the Kalman filter to fuse (make the best use of) all the data from each of the sensing elements, the attitude sensor output the real-time attitude angles relative to its own reference frame, including the pitch, roll and yaw (as shown in Fig. 1) precisely.

Considering that the registration of multi-view scans is a process for determining the relative orientation and position between the scans, we study the applicability of the miniature attitude sensor for facilitating in-process range image registration. The attitude sensor, which captures its own orientation changes, is fixed on the scanner. Since the MEMS attitude sensor is extremely compact and could easily be built into a scanner assembly, it can actually be invisible to the users. With the aid of the attitude sensor, our registration algorithm automatically aligns the dense points taken in the current measurement to the point set prior obtained, without the need of any markers or other auxiliary devices. In the following sections, we will explain how the scheme works and demonstrate its performance via experiments.

## 2. Method overview

In the proposed measuring strategy, we change the scanner to different positions and orientations to cover the object to be digitized and do not move the object dur-