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Direct transformation of coordinates for GPS positioning using the techniques of genetic programming and symbolic regression

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Abstract

Transformation of coordinates usually invokes level-wised processes wherein several sets of complicated equations are calculated. Unfortunately, the accuracy may be corrupted due to the accumulation of inevitable errors between the transformation processes. This paper presents a genetic-based method for generating regressive models for direct transformation from global positioning system (GPS) signals to 2-D coordinates. Since target coordinates for a GPS application can be obtained by using simpler transformation formulas, the computational costs and inaccuracy can be reduced. The proposed method, though does not exclude systematic errors due to the imperfection on defining the reference ellipsoid and the reliability of GPS receivers, effectively reduces the statistical errors when the accurate Cartesian coordinates are known from the independent sources. From the experimental results where the target datums TWD67 is investigated, it seems that the proposed method can serve as a direct and feasible solution to the transformation of GPS coordinates.

Keywords: Soft-computing; Symbolic regression; Genetic programming; GPS; Regression; Coordinate system

1. Introduction

The global positioning system (GPS) (EI-Rabbany, 2002) is a satellite-based navigation system made up of a network of 24 satellites which broadcasts precise timing signals by radio to GPS receivers, allowing users to determine their locations on Earth. With the popularity of general purposed GPS receivers becoming consumer electronics, GPS has been emerging as a convenient tool for positioning and navigation. Positioning by GPS is carried out in three-dimensional (3-D) geocentric Cartesian coordinates, X, Y, and Z, which is calculated and transmitted to the receivers as coded information. Signals from a general purposed GPS receiver are usually encoded according to the NMEA-0183 standard, carrying positioning information (longitude, latitude, altitude, etc.) in WGS84 (DMA, 1987). As in practical applications of positioning or navigation, it is frequently required to convert the coordinates derived in one geographic coordinate system to the values expressed in another. Coordinates obtained from a GPS receiver also need to be converted if the target coordinates are described in a different way.

Transformations between various coordinate systems involve not only complex, usually non-linear, algebraic formulas, but also some very specific numerical parameters which have been established officially as national and continental geodetic *datums*. If necessary, the transformation process performs level-wise conversions, starting from the source coordinates to the target coordinates, where each level of conversion takes care of a mapping from one coordinate system to another. Unfortunately, some transformation formulas for specific areas are based on estimation and inherently of errors; and therefore, positioning accuracy is degraded as such errors are accumulated during the transformation process. The more steps for transformations, the more inaccuracies. From the aspect of computational costs, the more steps for transformations usually result in more power consumption; which is a serious problem when GPS is applied to mobile applications.

This study tries to eliminate the levels needed for the transformation of coordinates and to produce a condensed process for GPS positioning. Conceptually, the level-wise

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transformation process can be viewed as the composition of all transformation functions. Thus, there seemingly exists a set of transformation equations between the signals received from GPS and the target coordinates used in an application. This intuitively forms a problem of regression. If such formulas that perform fewer levels of transformation can be derived, the inaccuracies and computational costs may be reduced. In this paper, a genetic-based method is proposed for finding simpler formulas for direct transformation of coordinates from WGS84 to specific coordinate systems.

Notably, GPS-based positioning needs to consider at least two types of inaccuracy. Firstly, systematic errors exist due to the imperfection on defining the reference ellipsoid (Ashkenazi, 1986), though relative positioning with respect to standard reference points defined in the local datums is accurate and acceptable. Secondly, GPS has several sources of errors, such as the radio signal corruption caused by ionospheric delay, tropospheric delay, satellite clock and receiver clock offsets, receiver noise, receiver calibration and multipath, and the synchronization of positioning data from different tracking stations. Approaches that can partially reduce such errors have been proposed (Liou et al., 2001; Lundberg, 2001; Jwo et al., 2004; Yeh et al., 2006; Zhang et al., 2006). However, eliminating such errors mentioned above is not the scope of this paper.

The proposed method has been successfully applied, but not restrictedly, to the transformation of TWD67 (Tseng and Chang, 1999; MOI, 2006a, b). The experimental results show that the proposed method can serve as a direct and feasible solution to this problem. This study is not to find a single transformation method for reference systems. The same procedure can be applied to the transformation of other target coordinate systems, provided that accurate coordinates are known from independent sources.

Organization of the paper is as follows. In Section 3, the process of transformation from GPS signals to two-dimensional (2-D) coordinates is briefly introduced. In Section 4, we formulate the level-wise transformation process as a regression problem and define the objective functions. For producing target functional expressions, the proposed methods are presented in Section 5. The results of experiments are given in Section 6. Section 2 presents a brief review on the related works followed by the conclusions of this study in Section 7.

2. Related work

Finding regressive models is essential in many applications, such as Liu and Wang (2006), Yang et al. (2006), Wu et al. (2007), and Seghouane and Amari (2007). Among these applications, black-box methods, such as artificial neural networks (Tresp, 2000; Aksyonova et al., 2003) and support vector regression (Drucker et al., 1997; Collobert and Bengio, 2001), are widely employed. As mentioned before, black-box methods are not dedicated to describing the relationships between the inputs and outputs. White-box methods offer the feasibility to describe the relationships between inputs and outputs in functional expressions. Traditional methods like linear regression (Chien and Huang, 2006; Lindbom et al., 2001; Xiao et al., 2005) can serve as tools for finding regressive models. However, its accuracy and performance vary in different applications. Evolutionary-based methods like genetic algorithms and genetic programming are emerging methods for complex regressive problems, which usually gain satisfactory results under the control of sophisticated parameters. In GPS applications, few studies devoted on using genetic-based methods for coordinate transformations. Below a brief review on related methods using genetic programming is given.

Augusto and Barbosa (2000) presented the implementation of symbolic regression based on genetic programming. In order to offer more possibilities for solving complicated problems in technological and scientific applications. Ferreira proposed "gene expression programming (GEP)" which uses an array structure to represent the regressive tree (Ferreira, 2001). Zhou et al. (2003) extended the mechanism of GEP to find classification rules in functional expression. Korkmaz and Üçoluk (2004) retained global information of the promising solutions during the genetic search process and used the information to control the operation of crossover. Gustafson et al. (2005) improved the performance of genetic programming when searching for the symbolic regression via the analysis of dissimilarity and mating. Costa and Pozo (2006) proposed a new selection strategy, called $(\mu+\lambda)$-GP, of individuals for mutation, where λ descendants generated by μ parents will participate in the competition and be selected the best μ individuals as survivals.

3. Transformation of coordinates

Basically, to convert coordinates from 3-D space to 2-D space in the same reference system is to flatten the data points by projection. If data points are defined across different reference systems, e.g., between the Polar system and the Cartesian system, they have to be further converted. In this paper, source coordinates received from GPS are in WGS84 which are defined by latitude (ϕ_{84}), longitude (λ_{84}), and the height (h_{84}). The target coordinates are TWD67 in TM2 (Tseng and Chang, 1999) which is a 2-D geodetic datum based on GRS67 and has being widely used in many existing applications. When working with the transformation, geodetic coordinates in WGS84 are converted from Ellipsoidal system to Cartesian system, mapped according to the local datum, and flatten by 2°-Zone Transverse Mercator projection (TM2). Such level-wise transformation is briefed as follows.

When working with the transformation, geodetic coordinates in WGS84 are firstly transformed into geographic coordinates (X_{84}, Y_{84}, Z_{84}) using the following