氏　　名	神 山 雅 子
学位（専攻分野）	博士(学術)
学 位 記 番 号	総研大甲第740号
学位授与の日付	平成１６年３月２４日
学位授与の要件	数物科学研究科　統計科学専攻 学位規則第４条第１項該当
学 位 論 文 題 目	Adjustment of Sampling Locations in Rail-Geometry Datasets with Dynamic Programming and Non-Linear Filtering
論 文 審 査 委 員	主　査　教授　土谷　隆 教授　石黒　真木夫 教授　田村 義保 教授　樋口　知之 教授　吉村　彰芳（東京工科大学）

論文内容の要旨

The major purpose of this thesis is to adjust sampling locations in two rail-geometry datasets obtained by track-inspection cars. A special rolling stock called a track-inspection car periodically measures rail geometry in order to monitor rail geometry. This is because the railway track plays an important role in ensuring running safety of the trains and riding comfort of the passengers. Thus, railway companies must maintain the quality of their tracks against wear, tear, and so forth caused by the loads of the passing trains.

A track-inspection car continuously measures various aspects of rail geometry while running on the rails. These geometric measurements are simultaneously discretized at fixed spatial intervals, and are recorded as digital datasets. The set of their discretized locations on the rail changes slightly with each measurement although it is desirable that these locations be fixed in order to observe variations in rail geometry. This location gaps are based on the fact that the wheel-rotation pulse that is used to select the discretized locations is linked to the rotation of the car wheel. Thus, identical spatial discretization cannot be reproduced. Moreover, it is difficult to adjust these location gaps after the discretization. If the spatial intervals (called sampling intervals) between the discretized locations stay constant in two measuring runs, these gaps could be easily adjusted by calculating the correlation coefficient distance between the two datasets, even if the locations themselves change. In reality, however, some sampling intervals shorten or lengthen locally due to slipping or sliding of the car wheel, respectively. In addition, the length and location of these locally irregular intervals cannot be detected unfortunately. This makes it difficult to adjust the location gaps.

In this thesis a procedure is proposed to adjust the sampling locations in one spatially discretized dataset to the sampling locations in another when the differences between these sets are mainly caused by the sampling intervals that locally lengthen and shorten. This adjustment is formulated as an optimization problem that can be efficiently solved by dynamic programming. This formulation contains a few hyperparameters which are usually tuned by manual. Here these hyperparameters are identified automatically by using the Bayesian framework.

The developed procedure is described in more detail as follows. First, the adjustment problem is formulated as an alignment problem between the reference dataset and the misregistered dataset. Then the alignment problem is reformulated as an optimization problem which can be solved efficiently with dynamic programming.

Then, a Bayesian framework is introduced to determine the hyperparameters automatically. This idea is based on the observation that the optimal solution in dynamic programming is interpreted as the maximum a posteriori (MAP) estimate in

a certain Bayesian model with the specific values of the hyperparameters. With this framework, the hyperparameters are estimated with the maximum likelihood procedure for the associated Bayes model by employing the non-linear filtering procedure for a generalized state-space model.

This approach appears to work reasonably well in detecting sliping and sliding of the wheels in view of the MAP estimate. But by taking a closer look, it turned out that the procedure gives unsatisfactory results in view of the smoothing (predictive) distribution of the adjusted data points.

In order to resolve this problem, a refined Bayesian model is introduced. The hyperparameters in this model are classified into two categories: the one representing the state of the wheel rotation, and the other representing the noise from the measuring device which is formulated as AR model. When all parameters are simultaneously estimated with the maximum likelihood procedure, the results indicated that too many slippng or sliding occurred in the misregistered dataset than expected. To overcome this difficulty, a procedure is developed that estimates the noise parameters directly from the difference sequence between the reference and the roughly adjusted sets. This procedure alternatively identifies the wheel rotation and the noise parameters until the internal inconsistency incurred in the model is eliminated. Plausibility of the smoothing distribution of the adjusted data points obtained with this procedure is demonstrated through application to real datasets.

論文の審査結果の要旨

本研究は，鉄道線路に沿って離散的に測定された軌条形状データセットが，同じ線路区間に対して複数あったとき，離散化（測定）位置のずれを推定して揃えるアルゴリズムを開発したものである．またその研究を通じて，動的計画法で最適化できる問題を一般状態空間表現に定式化することにより，問題に含まれる未知のパラメータを最尤法で決定できることを示したものである．申請者は線路形状検査監督業務に関する研究をほぼ一手に引き受けている機関（財団法人）に在職する軌道管理の専門家であり，本論文は,一見意外とも思える分野に統計科学的手法を適用し，その有効性を示して新しい応用分野を拓いたものである．

本来対応すべき複数のデータ点の対応を推定するデータ補正問題はこれまでにも種々の分野で取り扱われてきており，それらは最適化問題に定式化され，動的計画法で解くことが行われてきた．本論文は，まず，鉄道軌条形状データの有効利用に際して同種のデータ補正問題が潜むことを喝破した点，さらにそれを解決するにあたり，目的関数をベイズ的に解釈して対応する一般状態空間モデルを考えることで，動的計画法では統一的に取り扱うことのできなかった超パラメータの同定を最尤法で解決する一般的枠組みを与えた点において，新規性が認められる．また，実務的見地をもとに，観測ノイズの部分を自己回帰モデルで表現し，モデルを改良している点も興味深い．さらに，実務家としての立場から，提案した方法論を実際のデータに適用し，計算時間や効率性の観点からも十分な実用可能性を示している点が評価できる.また,現状では測定されていない運行情報の獲得を，それを測定するためだけに新しい機器の開発や設置をするといった，多額の投資でハード的に解決するのではなく，統計モデルを通してデータから推定できることを明確に示している点も，統計科学の論文として意義があるものである．これらの成果はすでに３本の論文(査読付き国際雑誌一編，査読付き国際会議録一編，査読付き国内雑誌一編)にまとめられ，出版あるいは採択されている．

以上述べてきたことより，本論文は，博士(学術)を授与するに十分な内容であると判断する．