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Establishing a Real-time Precise Point Positioning Early Warning System

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Abstract

Real-Time Early Warning Systems are a critical approach implemented for monitoring geo-hazard disasters such as earthquakes, tsunamis, volcanic activities, and land subsidence. The Earth's population has experienced a substantial increasement, consequently exposing a growing number of people to the effects of various geo-hazard disasters. These influences could impact citizens and countries at different severity levels, reaching high costs in terms of human beings and economic losses. However, the early warning system's ability to initiate proper and reliable warnings significantly impacts in disaster cost reductions in terms of saving lives, reducing home and infrastructure damages, and mitigating economic losses.

Real-Time Precise Point Positioning (RT-PPP) plays a significant role as part of the Early Warning Systems, due to its potential to provide real-time tracking and global coverage and its reliance on precise real-time measurements acquired from only one receiver. However, the RT-PPP approach applies State Space Representation (SSR) products that are highly sensitive to several GNSS error sources. As a result, the warning system's availability and reliability are negatively impacted. It may even be triggered to issue false warnings by factors such as long initialization times, convergence losses, due to poor quality of orbital and clock corrections, ambiguity resolutions, or/and multipath error. Furthermore, poor satellite geometry and the latency of SSR products severely affect the performance of real-time PPP positioning.

In this research, we investigated the effect and mitigation of latency on real-time correction products. The International GNSS Services (IGS) provides official real-time products for RT-PPP; these products contain clock and orbit corrections, among others, and they are the main research concerns as the combination process increases the latency impact on both RT-PPP results and influences the early warning systems performance based on this positioning technique. In this research, investigations into the potentiality of using machine learning approaches to overcome latency problems were carried out. The research examines the Support Vector Regression (SVR) and Autoregressive Integrated Moving Average (ARIMA) machine learning models to predict the corrections broadcasted in SSR products that have a big capability in order to be used instead of the corrections impacted with latency.

The prediction process requires the implementation of rolling sliding windows for training and parametrization of the research machine learning models. Next, the research has investigated the establishment of RT-PPP early warning systems with the aid of machine learning. The deformation simulation engine was created during the research, which was then utilized through a series of experiments to obtain an adequate RT-PPP scenario for research database creation. The created database is consequently used to train and test several machine learning models and their influences on the early warning system performance.

The research results regarding latency showed that the SVR and ARIMA models could mitigate the latency influences for the primary navigation satellite systems GPS and GLONASS by around twenty percent. The SVR model showed a tendency to predict outliers; however, the execution time for the SVR is significantly faster than the ARIMA model processing time.

Regarding the performance of the RT-PPP early warning system, the research statistically evaluates several machine learning models, including decision tree, random forest, support vector classifier, K nearest neighbors, logistic regression, and extreme gradient boosting models as machine learning approaches for establishing an early warning system. The extreme gradient boosting and random forest models were more accurate than the other utilized models, with 97 and 99 percent overall accuracy. At the same time, the extreme gradient boosting showed less tendency to initiate false alarms, with 2.48 percent compared to 16.28 percent for the random forest model.

From the research findings, we derived a set of statistical assessments to evaluate the performance of the established early warning systems. These statistical assessments can evaluate the ability of the utilized machine learning models regarding deformation detections and the model's tendency to initiate false warnings. The study's results confirmed that extreme gradient boosting is the most effective machine learning technique for creating an early warning system. The research contributions can benefit citizens, businesses, stakeholders, and government agencies.

Landslides, land uplifting, volcanic activity, earthquakes, and tsunamis are only some of the geo-natural hazards where the aid of the RT-PPP early warning system can be established. This thesis' findings can also aid emergency planners and managers by providing them with more accurate descriptions of real-time warnings, enhancing the understanding of the likely extent of deformations extents and their impacts.