

Contents

| | |
|--|----|
| Chapter 1 Introduction | 1 |
| 1.1 Scientific background | 2 |
| 1.1.1 GPS solution approaches | 2 |
| 1.1.2 Strong-motion data solution approaches | 4 |
| 1.1.3 Integration of GPS and accelerometer observations | 6 |
| 1.2 Aims and objectives | 7 |
| 1.2.1 Augmentation approach | 7 |
| 1.2.2 Integration approach | 7 |
| 1.2.3 Adaptive approach | 8 |
| 1.2.4 The key issues about integration | 8 |
| 1.2.5 The relationship between baseline shift and ground tiling | 8 |
| 1.3 Organization of the book | 8 |
| Chapter 2 Real-time monitoring the ground motion using GPS with real time corrections | 11 |
| 2.1 Introduction | 11 |
| 2.2 Methodology | 12 |
| 2.2.1 The velocity determination model based on broadcast ephemeris | 12 |
| 2.2.2 Extracting corrections from the reference station | 13 |
| 2.2.3 The velocity determination model based on reference station correction | 14 |
| 2.2.4 Retrieve the final true velocity and displacement | 15 |
| 2.2.5 The data processing flow of the augmentation approach | 15 |
| 2.3 Experiment analysis | 16 |
| 2.3.1 Comparison of displacement and velocity between GPS and strong-motion sensor | 17 |
| 2.3.2 Comparison of displacement and velocity results between different sample rate data | 17 |
| 2.3.3 Comparison of GPS results between the single station method and augmentation method | 18 |

| | |
|---|-----------|
| 2.3.4 Comparison of the observation residuals and initial trend drift correction | 20 |
| 2.4 Conclusion | 22 |
| Chapter 3 Application of a net-based baseline correction scheme to strong-motion records of the 2011 Mw 9.0 Tohoku earthquake | 23 |
| 3.1 Introduction | 23 |
| 3.2 Methodology | 26 |
| 3.2.1 Selection of reference records | 26 |
| 3.2.2 Net-based correction on target records | 28 |
| 3.2.3 Detection of outlier records | 28 |
| 3.3 Application to strong-motion data for the 2011 Mw 9.0 Tohoku earthquake | 29 |
| 3.3.1 Data | 29 |
| 3.3.2 Selected reference records | 30 |
| 3.3.3 Augmented target records | 30 |
| 3.3.4 Outlier records | 34 |
| 3.3.5 Improvements over the previous empirical approaches | 35 |
| 3.4 Conclusion and discussion | 40 |
| Chapter 4 Cost-effective monitoring of ground motion related to earthquakes, landslides or volcanic activity by joint use of a single-frequency GPS and a MEMS accelerometer | 42 |
| 4.1 Introduction | 42 |
| 4.2 Method | 44 |
| 4.3 Outdoor experiments | 45 |
| 4.4 Discussion and conclusions | 50 |
| Chapter 5 A new algorithm for tight integration of real-time GPS and strong-motion records, demonstrated on simulated, experimental and real seismic data | 52 |
| 5.1 Introduction | 52 |
| 5.2 Mathematical model | 54 |
| 5.3 A new approach to combine GPS and seismic accelerometer data | 57 |
| 5.4 Validation and analysis | 58 |
| 5.4.1 Simulated dataset | 58 |
| 5.4.2 Experimental Test | 59 |

| | |
|--|-----------|
| 5.4.3 Application to a real earthquake: El Mayor-Cucapah Mw 7.2, 2010 | 62 |
| 5.5 Summary and discussion | 65 |
| Chapter 6 Adaptive recognition and correction of baseline shifts from collocated GPS and accelerometer using two phases Kalman filter | 67 |
| 6.1 Introduction | 67 |
| 6.2 Methodology | 69 |
| 6.2.1 The model for tight integration of GPS and strong-motion measurements | 69 |
| 6.2.2 The adaptive recognition of baseline shifts in strong-motion records | 70 |
| 6.2.3 The implementation process | 74 |
| 6.3 Validation | 75 |
| 6.3.1 Experimental test using a shaking table | 75 |
| 6.3.2 Application to a real earthquake: 2011 Mw 9.0 Tohoku earthquake | 77 |
| 6.4 Conclusion | 81 |
| Chapter 7 An improved loose integration method of coseismic waves retrieving from collocated GPS and accelerometer | 82 |
| 7.1 Introduction | 82 |
| 7.2 Overview of the traditional loose integration method | 83 |
| 7.3 The improved loose integration method | 84 |
| 7.4 Validation and analysis | 85 |
| 7.5 Conclusion | 88 |
| Chapter 8 An improved method for tight integration of GPS and strong-motion records: complementary advantages | 90 |
| 8.1 Introduction | 90 |
| 8.2 Methodology | 92 |
| 8.2.1 Using GPS to estimate baseline shifts for the strong-motion sensor | 92 |
| 8.2.2 Using acceleration to constrain GPS solution and ambiguity- resolution | 94 |
| 8.2.3 The implementation process of the method | 94 |
| 8.3 Validations | 95 |
| 8.3.1 Analysis of the baseline shift | 96 |

| | | |
|-------------------|--|-----|
| 8.3.2 | Analysis of the displacement time series | 97 |
| 8.3.3 | Analysis of the zenith tropospheric delay | 99 |
| 8.3.4 | Analysis of the waveforms | 99 |
| 8.4 | Conclusions and discussions | 101 |
| Chapter 9 | The study of key issues about integration of GNSS and strong-motion records for real-time earthquake monitoring | 103 |
| 9.1 | Introduction | 103 |
| 9.2 | Method and Data | 105 |
| 9.3 | Validation and analysis | 105 |
| 9.3.1 | Coordinate system | 106 |
| 9.3.2 | GNSS sampling rate | 106 |
| 9.3.3 | The constrain of the dynamic noises | 107 |
| 9.3.4 | GNSS data quality | 108 |
| 9.3.5 | Convergence speed | 109 |
| 9.3.6 | Ambiguity resolution | 110 |
| 9.4 | Conclusions and discussions | 111 |
| Chapter 10 | The study of baseline shift error in strong-motion and ground tilting during co-seismic period based on GPS observations | 112 |
| 10.1 | Introduction | 112 |
| 10.2 | Extracting strong-motion baseline shift based on GPS observation | 114 |
| 10.3 | Extracting of ground tilting information based on GPS observation | 115 |
| 10.4 | Validation and analysis | 116 |
| 10.4.1 | Experiment introduction and data processing | 116 |
| 10.4.2 | Result analysis | 117 |
| 10.4.3 | A case study of the earthquake event: 2011 Mw 9.0 Tohoku-Oki earthquake | 119 |
| 10.5 | Conclusion | 123 |
| Chapter 11 | Comparison of high-rate GPS, strong-motion records and their joint use for earthquake monitoring: a case study of the 2011 Mw 9.0 Tohoku earthquake | 125 |
| 11.1 | Introduction | 125 |

| | | |
|---|--|------------|
| 11.2 | Datasets and processing approaches | 126 |
| 11.2.1 | Data description | 126 |
| 11.2.2 | Processing approaches | 127 |
| 11.3 | Results and analysis | 128 |
| 11.3.1 | Comparison of horizontal co-seismic movement | 128 |
| 11.3.2 | Comparison in time-frequency domain of the displacement time series | 129 |
| 11.3.3 | Comparison of velocity waveforms | 130 |
| 11.3.4 | Comparison of P wave detection | 130 |
| 11.4 | Conclusions and discussions | 134 |
| Chapter 12 | Synthesis | 135 |
| 12.1 | Conclusions | 135 |
| 12.1.1 | GPS velocity estimation augmentation approach | 135 |
| 12.1.2 | Strong-motion net-based augmentation approach | 136 |
| 12.1.3 | Loose integration of GPS and strong-motion observations | 136 |
| 12.1.4 | Tight integration of GPS and strong-motion observations | 136 |
| 12.1.5 | Adaptive integration of GPS and strong-motion observations | 137 |
| 12.1.6 | Improved loose integration of GPS and strong-motion obser- vations | 137 |
| 12.1.7 | Improved tight integration of GPS and strong-motion obser- vations | 138 |
| 12.1.8 | Key issues of integration of GPS and strong-motion obser- vations | 138 |
| 12.1.9 | Relationship between baseline shifts and ground tilting | 139 |
| 12.1.10 | Comparison of different sensors for earthquake monitoring and early warning | 139 |
| 12.2 | Outlook | 140 |
| 12.2.1 | Study the earthquake early warning model | 140 |
| 12.2.2 | Study the integration of multi-sensor and data quality control | 140 |
| 12.2.3 | Develop a new sensor and real-time application system | 140 |
| Acronyms and abbreviations | 141 | |
| References | 143 | |