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Maximizing Recording Efficiency of ICEARRAY Using Common-triggering

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Abstract

Traditional arrays using a central recording facility and dedicated communications channels to continuously record data are expensive to deploy and maintain. A lower cost alternative is to install a network of low-cost stand-alone instruments, each operating in a 'triggered recording' mode with local storage and near-real-time generic communications. Natural and cultural conditions generally result in varying background noise levels across the sites of a given network. Therefore, event detection and recording should be optimized to produce complete data sets, even for frequent small and local earthquakes, without creating masses of spurious records at individual nodes. We achieve this by employing a tuned "common-triggering" (CT) scheme, effectively converting a network of isolated instruments into an array. Selected instruments are configured to send trigger notification messages over the Internet to one or more central hubs, each running a CT detection algorithm. Within the CT detection algorithm, each received trigger notification message results in a preset number of 'votes' being added to a tally. The number of votes being added depends on the known triggering quality of the node sending the alert package. Whenever a preset number of votes are received within a moving time window, a global trigger command is issued to all instruments within the network. The CT scheme was implemented for the ICEARRAY, the first small-aperture, strong-motion array in Iceland, consisting of 14 CUSP-3Clp broadband, triaxial, strong-motion accelerographs equipped with GPS based timing and perpetual GPRS Internet communications. The recordings of the 29 May 2008 Ölfus earthquake show that the CT-scheme maximizes the array's efficiency in recording real events while minimizing the analyst's efforts in reviewing data. This system markedly improves the usefulness of a network of stand-alone instruments by converting them into an array with little or no additional cost and allows sites with marginal triggering suitability to be effectively incorporated as slave instruments.

Introduction

The ICEARRAY, the first small-aperture strong-motion array in Iceland, installed in the South Iceland Seismic Zone (SISZ) for the specific purpose of establishing quantitative estimates of spatial variability of strong-motions, and investigating earthquake rupture processes and source complexities of future significant earthquakes in the region. The ICEARRAY has been in operation since October 2007 and was installed in the village of Hveragerdi on the western edge of the SISZ (see Figure 1). The SISZ is collocated with high population densities in numerous towns and villages along with the infrastructure essential to a modern society. As a consequence, the seismic risk in Iceland is highest in the SISZ.

The optimal ICEARRAY geometry and number of stations was attained via analyses of the corresponding array transfer functions and their properties. The final layout of the array, shown in Figure 1, comprises N = 14 stations over an area of aperture D = 1.9 km with the smallest inter-station distance of d = 50 m.

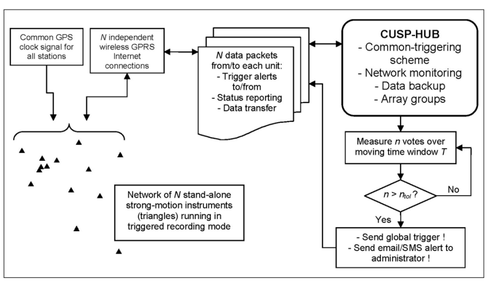

Figure 2 – A schematic view of the information flow to/from a network (ICEARRAY) of N stand-alone instruments, perpetually connected to the Internet and monitored by a central hub running a Common Triggering System. The instruments send trigger notification messages to the central hub and then upload the data to it after recording. The central hub determines the incoming trigger alert's source and according to this adds a preassigned number of votes to a tally. Once ntol votes are accumulated within a moving window of duration T, the "common-triggering" system issues a global trigger to all instruments and alerts an administrator.

Common-Triggering Scheme

ICEARRAY was initially operated as a network of stand-alone stations with very similar triggering criteria and levels. Two issues were apparent from the outset: (1) Earthquakes producing weak-ground motions (local, small and nearby earthquakes) were not picked up by all stations; (2) The low triggering levels resulted in a large number of "false" triggers.

The issue can be solved and record completeness attained through the application of a "common-triggering" system on the array, implemented as follows (see also Figure 2):

- within the CT hub's database each instrument in a defined "common-triggering" network is assigned a number of votes that are to be generated when that instrument triggers
- whenever a triggering event is encountered on an instrument within the defined "common-triggering" network, the instrument begins recording data and sends a small TCP/IP data packet over the Internet to the central CT hub
- the CT hub receives the trigger notification messages and determines the source of the trigger for each notification message received
- once the source has been determined the number of votes assigned to that source are added to a vote tally within a moving time window
- once a preset number of votes, n_{tol}, are received within a preset time window a global triggering event is determined and small TCP/IP packets are sent to all instruments within the triggering network telling them to begin recording
- each instrument will then begin recording (if not already recording) and respond with trigger-acknowledge TCP/IP packets

Performance Analysis of the Common-Triggering Scheme

At 15:45 on May 29th, 2008, a magnitude 6.3 earthquake struck between Hveragerdi and Selfoss (see Figure 1). The ICEARRAY recorded the main shock on 11 stations and over 600 aftershocks. At present, this data comprises the largest part of ICEARRAY's dataset of 2933 recordings since October 1st, 2007 However, when including only triggers on three stations or more the ICEARRAY has recorded 1046 datafiles since October 1st 2007 until June 5th 2008.

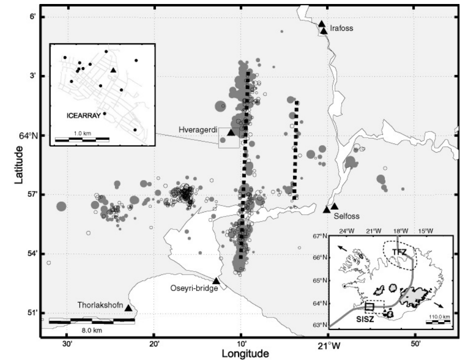

Figure 1 – The small map inset at bottom right shows Iceland, an island in the North Atlantic Ocean (with glaciers shown shaded), in reference to the present-day boundary of the Eurasian and North American tectonic plates. Their relative motion is ~2 cm/year, in the direction indicated by the arrows. The solid rectangle within the SISZ indicates the macroseismic area of the Ölfus earthquake of 29 May 2008 (shown in the larger map) where the recording sites of the ICESMN are denoted as triangles and those of the ICEARRAY as dots (seen in the small map at top left along with the street layout of Hveragerdi). The approximate locations of the causative faults are indicated by the thick dashed lines. The aftershocks that occurred during the time periods analyzed in this study are shown as gray circles (events from 29 May at 16:01 to 1 June at 8:35) and open circles (events from 1 June at 8:40 to 3 June at 11:40). The diameter of the circles indicates their relative magnitude differences.

Shortly after the main shock the CT scheme on the CUSP-HUB ceased operation for unforeseen technical reasons, specifically between 2008/05/29 16:01 to 2008/06/01 08:35, during which period 1055 triggers were issued to the central hub. While this was unfortunate in terms of data capture, the failure period has allowed the effectiveness of the CT scheme to be analyzed. The result is shown in Figure 3a, where, to achieve consistency over the analysis period, we have removed sites that were non-operational or that suffered from intermittent communication related problems within the period, leaving 7 stations with 100% uptime. Figure 3a shows the number of recordings captured simultaneously (start-time within 10 s from first to last record) and indicates clearly that the number of stations capturing any particular event varied greatly. On the other hand, once the CT scheme had been reinstalled, complete station coverage for each event was nearly achieved, as can be seen from Figure 3b which covers the time period of 2008/06/01 08:42 to 2008/06/03 11:40. As in Figure 3b stations have been removed leaving 8 instruments with 100% uptime over the period. The few incidences of 6 and 7 station datasets in Figure 3b are caused by the failure of the global trigger message to be received in time due to delays in the communications network.

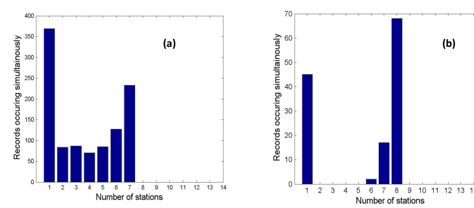

Figure 3 – The number of ICEARRAY stations simultaneously recording (starting within a 10 second moving time window) aftershocks of the 15:45 May 29, 2008, M6.3 earthquake near Hveragerdi, South Iceland, and had 100% uptime status during (a) 2008/05/29 16:01 to 2008/06/01 08:35 without CT; and (b) 2008/06/01 08:42 to 2008/06/03 11:40 with CT.

Figure 4 shows the number of global triggers that the CT has issued on the ICEARRAY over a period of 6 weeks from 15/06-29/07/2008, along with the number of additional, isolated, trigger alerts for each instrument. All the instruments have similar triggering criteria and levels, and it is clear that some sites are noisier than others. The alerting system of the CUSP-HUB running the CT scheme has resulted in the analyst viewing only those recordings that were associated with global triggers. The other triggers can be discarded and therewith the data. Even with the present non-optimized setup of the CT system, considerable data-reviewing effort on behalf of an analyst has been saved. Spot-checking of a number of those additional triggers revealed no real events. The bar-plot also indicates that sites IS602, 603, 608, 609 and 613 are the most reliable sites i.e., have the smallest number of false triggers, and in future these sites should be assigned a high number of votes.

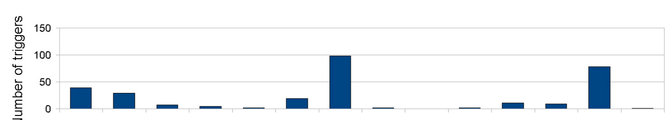

Figure 4 – The number of triggers on ICEARRAY from 15/06-29/07/2008. The column at left shows the number of global triggers issued by the CT scheme, while the other columns show individual triggers from each instrument of the ICEARRAY that did not cause a global trigger. Site IS608b is not included in the array.

Conclusions

In the "common-triggering" scheme the instruments of a network of stand-alone instruments are configured to send trigger notification messages to one or more central hubs running a CT-algorithm that accepts the trigger notification messages. Each message is decoded to find its source and a preset number of votes are added to a tally. Whenever a preset number of votes have accumulated within a specified moving time window a global triggering command is issued to all instruments within the network. Thus, the CT-scheme operating over the Internet maximizes the efficiency of the triggering system of a network, effectively converting it into a triggered array, recording significant (real) events only, with the added benefit of significantly minimizing the analyst's efforts in reviewing recorded data by separating earthquake recordings from noise. This system markedly improves the usefulness of a network of stand-alone instruments with little or no additional cost and allows sites with marginal triggering suitability to be effectively incorporated as slave instruments.

Acknowledgements

This work was funded by Canterbury Seismic Instruments Ltd., the 6th Framework of the European Commision through the Marie Curie International Re-integration Grant (MC-IRG), contract No. MIRGCT-2006-036564; the Icelandic Centre for Research (RANNIS) Project Grant No. 60043021; the University of Iceland Research Fund; and the Síminn telecommunication company in Iceland.