

MCEER RESEARCH TASK STATEMENT

Thrust Area: 3

Budget:

9.3.2a ImageCat, Inc.

9.3.2b UCI

Houshmand

EarthData

GWU

Yr 9 Assigned

Project Number: 9.3.2

Task Title: Remote Sensing and Advanced Technology for Disaster Mitigation, Response and Recovery

Investigators: Ronald T. Eguchi*, Masanobu Shinozuka, Bijan Houshmand, Jim Reis and Ray Williamson

Institutions: ImageCat, Inc., UCI, UCLA, EarthData, and George Washington University

* *indicates task leader*

Statement of Project Goals: *(Conceptually describe what the work is intended to accomplish, in 100 words or less. Do not provide detailed description here.)*

This task focuses on the development and application of remote sensing technologies for post-disaster damage detection, building inventory development, and rapid loss estimation. Ultimately, these technologies will be integrated into real-time decision support systems. In order to validate the damage detection methodologies, data are being used from the recent Indian Ocean tsunami, and a comprehensive set of earthquakes including the: 2004 Niigata (Japan); 2004 Al Hoceima (Morocco); 2003 Bam (Iran); 2003 Boumerdes (Algeria); 2001 Bhuj (India); 1999 Chi-Chi (Taiwan); 1999 Marmara (Turkey); 1995 Kobe (Japan); and 1994 Northridge events. Additional multi-hazard funding support is sought during Year 9, to extend these post-disaster damage assessment capabilities to windstorm (Hurricane Charley and Hurricane Ivan) and the Indian Ocean tsunami. As part of this additional funding, the research team (Williamson) also intends on developing a position paper that will identify alternative strategies for transitioning MCEER into multi-hazard research in the area of remote sensing.

Problem Description and Research Approach of Proposed Work for Year 9: *(Detailed description of research to be conducted and methodology to be used.)*

It is increasingly recognized that remote sensing technologies have a critical role to play in disaster mitigation, response and recovery. Preliminary studies in Russia and the U.S. suggest that prior to an earthquake, satellite and airborne imagery is a source of critical infrastructure data for developing building and lifeline inventories. Researchers in the US, Japan and Europe have demonstrated how, after an event, satellite imagery provides a 'quick-look' regional overview of urban damage. Building damage has been identified on moderate-resolution optical (Landsat and SPOT) and SAR (ERS) imagery for Marmara, Turkey and most recently, high-resolution coverage (Quickbird and IKONOS) of Boumerdes, Algeria and Bam, Iran. Moving forward, it is anticipated that remotely-sensed data will increasingly support preparedness activities, streamline post-earthquake reconnaissance, facilitate more effective decision-making, and ultimately, reduce losses and save lives by improving the overall response.

In general terms, this research task is working towards the use of advanced technologies in real-time reconnaissance and decision support systems. Research is investigating the application of these technologies during: (a) the immediate response period (initial days following a large earthquake); (b) the early recovery period (several weeks following the earthquake); and (c) as a key component of longer-range mitigation and preparedness programs. The study approach seeks to identify ways in which decisions made during these disaster phases, together with the timeframe within which they are made, can be improved through integrating remote sensing technology.

Specific Year 9 assignments are as follows:

Eguchi – The following Year 9 tasks will be performed: (1) standardize pixel- and object-based damage detection algorithms for multiple earthquakes; (2) develop a 3D visualization-based methodology for detecting building damage states other than complete collapse (e.g. pancaking); (3) develop a city-wide stereo-satellite building inventory algorithm that automatically characterizes square footage, height and number of stories for residential commercial and industrial structures in the US and overseas; (4) investigate multi-sensor data integration (e.g. QuickBird, IKONOS and OrbView) for accelerated damage detection, and more robust building inventory characterization; (5) extend damage detection and building inventory methodologies to windstorms (hurricanes) and tsunamis.

Houshmand – Year 9 research addresses the use of spaceborne SAR remote sensing for rapid damage detection, and the use of SAR-derived topography for assessing coastal hazards due to tsunami threats, rising water levels, coastal erosion, and high winds. Year 9 efforts will focus on the development of algorithms that will automatically generate post-disaster coherence maps for urban environments. The use of digital elevation models (DEM) for coastal population centers for the purpose of assessing vulnerability will be explored in Year 9. Currently, a SAR-derived DEM is available for most of the world. These data - acquired during a recent Shuttle Radar Topography mission (SRTM) - will be used in the coastal multi-hazard investigation.

Shinozuka – Year 9 activities will continue to develop and improve methods of digital image processing that pertain to urban damage assessment and, in particular, the detection of specific structural damage conditions using SAR imagery. The comparison of pre- and post-disaster SAR images will be made in order to understand those factors that are key in describing significant damage states; in Year 9, interferometric SAR methods will be used to enhance the efficiency of the damage identification process. This method will be verified using data from the 2003 Bam, Iran earthquake where numerical results and key SAR imagery features will be delineated. In addition, the research team will continue to use the X-Patch code to simulate different damage scenarios. The goal of this activity will be to develop a comprehensive catalog of SAR images, albeit simulated, for different damage states.

EarthData – In Year 9, EarthData will provide several sets of imagery: Airborne SAR for the Los Angeles area; LIDAR data for several coastal areas, including south Orange County; archival data from the World Trade Center attacks.

Ray Williamson (Research Professor of International Affairs and Space Policy in the Space Policy Institute of The George Washington University) – We are asking Ray Williamson – who is very familiar with U.S. policies on satellite use for natural hazard mitigation – to develop a position paper for MCEER that will map out alternative strategies for

expanding current remote sensing research to other hazards, including manmade threats. Professor Williamson just completed a study for NASA and NOAA where he assessed the socioeconomic benefits of Earth science and applications research (using NASA and NOAA sensors) in reducing the risks and costs of natural disasters in the U.S. His findings will provide the basis for a more effective plan to transition MCEER into multi-hazard research in the area of remote sensing.

Assessment of State-of-the-Art: *(Describe other relevant work being conducted within and outside of MCEER, and how this project is different.)*

The research conducted by MCEER is unique within the U.S. research community. Overseas, studies concerning the use remote sensing technologies for post-earthquake damage detection are being conducted by Chiba University and the Earthquake Disaster Mitigation Research Center (EDM) in Japan, and by European researchers at Cambridge University (UK), the University of Bologna (Italy), and the research division of Benfield Group (UK). Collaborative research with Chiba University, EDM, the University of Bologna, Benfield and Cambridge University is currently being undertaken for the 2003 Bam, 2003 Boumerdes and 1995 Kobe earthquakes.

Researchers in Europe are exploring the use of remote sensing for characterizing urban structures. However, these studies are concerned with detailed architectural rendering using photogrammetric techniques, rather than the extraction of quantitative measures for building inventory. Many of the existing approaches employ airborne rather than satellite imagery. The research team is exploring a potential collaboration with the University of Pavia (Italy) to develop more efficient techniques of quantifying building inventories for large geographic regions or areas.

Progress to date: *(If applicable, a short description of achievements in previous years. Clearly distinguish progress achieved in the past year, i.e., accomplishments from April 1, 2004, to March 31, 2005.)*

Eguchi:

During the first eight years of research, major research accomplishments include: (1) developing preliminary pixel- and object-based post-earthquake damage detection algorithms that use optical and SAR data to locate and count the number of collapsed urban structures; (2) integrating GPS and SAR data in the assessment of post-earthquake ground displacements and building damage; (3) extracting building inventory data for US cities, using IfSAR and mono-satellite imagery; and (4) integrating remote sensing-derived building inventory data into existing loss estimation programs such as HAZUS'99.

Considerable progress has been made with the use of optical and radar imagery to detect and quantify earthquake damage after major earthquakes. Initial research conducted following the 1999 Marmara event shows that a comparative analysis of 'before' and 'after' ERS and SPOT satellite imagery reveals city-wide urban damage. The project team devised and validated quantitative optical and SAR change detection indices for the Turkish cities of Golcuk and Adapazari, expressing the concentration of building collapse as a function of indices including: difference, correlation, block correlation and coherence. Measurement-, feature- and decision-fusion techniques were tested for enhancing damage detection capabilities. Following the 2003

Boumerdes and Bam earthquakes, the basic damage detection methodology was extended to include very high-resolution QuickBird imagery. Resolution-driven modifications were made to the existing algorithms, including the integration of edge-detection filtering and texture analysis. The vision of a 'tiered reconnaissance system' was conceived, whereby satellite imagery offers a 'quick-look' regional damage assessment, which in turn provides a focus for the detailed inspection of damage on a per-structure basis. **During Year 8**, research activities have focused on the second phase of the tiered reconnaissance approach. With the aim of quantifying the number and square footage of buildings that collapsed during the Bam earthquake (valuable statistics that were unavailable after the event), pixel-based damage detection methodologies have been augmented with a new object-based approach. A semi-automated processing algorithm has been devised that treats each building as a separate "object". Damage is detected by comparing the spectral and textural characteristics of each object before and after the event. Square footage is estimated using the footprint area of building collapse and story height computed as a function of building shadow length. Preliminary results for the number and square footage of collapsed buildings have been obtained.

For building inventory, city-wide square footage and height characteristics of residential, commercial, and industrial areas in Los Angeles have been quantified using 'building height signatures' and 'building inventory plots'. The former is a cumulative sum of total building footprint area by building height (obtained from airborne IfSAR elevations). The latter is the total footprint area associated with specified story heights. A methodology has been developed for replacing the default databases in HAZUS'99 loss estimation software. **During Year 8**, a new building inventory tool named "MIHEA" (mono-image height extraction algorithm) has been developed for quantifying the square footage, height, and number of stories for individual buildings. Results have been validated for an area of downtown San Diego.

With the objective of determining whether damage to the urban environment can be discerned by merging data from different sources and technologies, displacement and strain field maps derived from SAR interferometry have been compared with those obtained from GPS measurements. Results for the 1999 Marmara (Turkey) earthquake suggest a positive association between areas exhibiting extreme ground displacement and severe building damage. However, since the scale of ground displacement is below the threshold of the smallest unit of measurement in the SAR data, it can not be used to separate ground displacement from urban damage. **During Year 8**, an algorithm has been developed for rapidly measuring ground surface displacement. The IfSAR interferogram tool has been tested for imagery of the 1999 Marmara earthquake.

Shinozuka:

The research team has published an ASCE paper in the Aerospace Division Journal that describes the use of various models (e.g., principal component, coherence analysis, and Bayesian-based Markov random field approach) with SAR data to identify damage to urban areas. The goal of this research is to develop more practical post-disaster, decision-making methodologies. These methods involve pattern recognition technologies that utilize wavelet formulations, and are facilitated by ARC/VIEW software. In a field experiment, a set of X-patch computer simulations of a bridge were compared with observed SAR data that were obtained from an airborne sensor (EarthData). Also, before- and after-event imagery (Envisat) of the Bam, Iran earthquake were collected and analyzed in order to test and evaluate different

damage detection methodologies. The majority of buildings in Bam were traditional one-story unreinforced adobe structures built of indigenous land material from the region. As a result, the corresponding SAR imagery of Bam reflected less material dependence on object detection. The backscattering, complex coherence, self-power and cross-power values were computed for each respective co-registered data pairs (i.e., before and after). The change detection scheme was applied to different city zones to evaluate whether damage patterns could be detected from these data. The ultimate goal of this research is to create damage maps that serve as important tools in managing the effects of large disasters. Field data were used to validate the findings of the before- and after-event comparisons.

Houshmand:

Year 8 progress included: (1) the development of guidelines for acquiring SAR remote sensing data for creating coherence maps (for damage assessment), (2) the establishment of effective ground resolution standards for generating coherence maps, and (3) assessing the damage detection capability (or power) of coherence maps for a variety of urban environments, e.g., densely populated; suburban, and rural. Also participated in monthly project team meetings with ImageCat and UCI.

Role of Proposed Task in Support of Strategic Plan: *(Describe how the effort will make a unique, useable contribution to the MCEER strategic plan.)*

The development of advanced technologies that quantify post-earthquake damage in near real-time is a critical step towards improving existing response and recovery procedures. Quantifying building inventory in an accurate and up-to-date manner will improve the reliability of existing loss estimation tools. As an element of MCEER's Thrust Area 3, these technologies will enhance community resilience, by: (1) helping emergency officials quantify the extent and severity of disaster impacted areas, in near real-time; and (2) contributing to decision support systems that prioritize response activities based on need, opportunity and available resources; and (3) supporting preparedness activities to identify vulnerable areas and devise mitigation strategies.

Task Integration: *(Describe how the work performed interfaces with other tasks and researchers funded by MCEER.)*

This task focuses on the development and use of advanced technologies for emergency response, recovery and mitigation. New tools and more comprehensive databases of the urban environment are required to reduce the losses from, and improve response to major disasters. Thrust Area 3 will result in better tools for emergency planners, officials, reconnaissance teams and recovery workers. This research also feeds into other decision-support tools being developed within Thrust Area 3. For example, providing community-based data (in the form of building and infrastructure databases) and immediate post-disaster impact information for the Recovery Tool that is being developed by Stephanie Chang at the University of British Columbia will be a high priority in Year 9.

As a result of this research, it is anticipated that planners will have access to better information on exposed assets, more reliable methodologies to project future earthquake losses, and real-time decision support systems that will identify post-earthquake damage within a matter of hours.

Possible Technical Challenges:

The technical challenges associated with testing and validating new technologies are considerable. While the limited nature of available data sets is a concern, verifying the efficacy of new technologies compared with conventional and perhaps, more accessible methodologies could create implementation issues. If successful, however, the potential for more accurate and timely post-event loss estimates is extremely high.

Anticipated Outcomes and deliverables:
(Also indicate those of particular benefit to IAB members and other end users.)

MCEER report documenting the development of building height signatures, building inventory plots, and the update of HAZUS'99 inventory data.

MCEER report and international journal paper (International Journal of Remote Sensing) documenting the development of an object-oriented algorithm for quantifying the number of square footage of damaged buildings in Bam.

Report documenting the development of MIHEA and a stereo-satellite city-wide inventory tool.

Case studies involving U.S. and foreign earthquakes.

Possible collaboration with California OES.

Potential end-users beyond academic community: *(IAB members and others.)*

Government Agencies: US-AID, USACE, FEMA, DOT, NASA, LA City, LA County, California Governor's Office of Emergency Services.

Professional Organizations: EERI.

Other: Insurance industry.

Educational outcomes and deliverables, and intended audience:

Workshops, briefings and seminars on the use of advanced technologies for post-earthquake damage detection. Intended audience: emergency responders, students and industry representatives. For examples, see Year 8 contributions to MCEER objectives.

Project Schedule and Expected Milestones for the Project: *(Milestones and estimated time of achievement; e.g. Fall, Spring, Summer.)*

- IJRS journal article documenting The Development of an Object-Oriented Approach to Building Damage Detection Using Very High-resolution Remote Sensing Technology, Autumn 2005.
- Report documenting The Development of an Object-Oriented Approach to Building Damage Detection Using Very High-resolution Remote Sensing Technology, Spring 2006.
- Report documenting The Development of MIHEA – A Mono-satellite Image Building Height Extraction Tool, Autumn 2005.
- Report documenting a City-wide Building Inventory Algorithm Based on Robust Multi-

satellite Image Integration, Summer 2006.

- Workshop presentation at the 4th International Workshop on the Use of Remote Sensing for Disaster Response and Recovery. Summer 2006.

Team Members: *(If known, provide names of team members associated with project including project leader, other faculty and their departments, undergraduate students, graduate students, postdoctoral students, industrial participants.)*

- Ronald T. Eguchi, ImageCat, Inc., Team Leader
- Beverley J. Adams, ImageCat, Inc.
- Charles K. Huyck, ImageCat, Inc.
- Howard Chung, ImageCat, Inc.
- Michael Z. Mio, ImageCat, Inc.
- Masanobu Shinozuka, UCI
- Jim Reis, EarthData
- Ray Williamson, George Washington University
- Pooya Sarabandi, Consultant
- Bijan Houshmand, Consultant
- Luca Gusella, Graduate Student, University of Bologna

Possible Direction of Work in Subsequent Years:

During Year 10, the team will continue transitioning earthquake-based research activities for multi-hazard application and implementation, and will extend the scope to consider man-made threats. Work will also concentrate on progressing damage detection and building inventory tools from preliminary to operational status.

Multi-Hazard Statement:

a) *(Conceptually describe in 200 words or less how some of the work you are conducting as part of your MCEER Year 9 research task can be exported/applied to other natural or man-made hazards including multi-hazard research.)*

The basic methodological approach employed by post-earthquake damage detection algorithms (i.e. changes between before and after satellite imagery) is directly applicable to other disasters, including windstorm and tsunami. However, there is a pressing need to understand the transferability of these techniques (damage detection and inventory development) to these additional hazards. For example, new optically-based damage scales may reflect alternate modes of structural damage, partial roof loss and debris distribution. These multi-hazard damage scales will, in turn, underpin the refinement and application of pixel- and object-oriented algorithms originally developed for earthquake. Performance of the multi-hazard algorithms can be validated using damage data collected during MCEER-funded VIEWS deployments following Hurricane Charley, Hurricane Ivan and throughout coastal regions of Thailand after the Indian Ocean tsunami. Using the MIHEA building inventory tool developed through MCEER funding, 3D damage characteristics can be explored for windstorm and tsunami. Using pre- and post-event imagery, disaster-related changes in building height and shape can be explored.

b) *If you are seeking supplemental multi-hazard funding, describe the multi-hazard milestones*

that you plan to complete as part of your Year 9 research.

The multi-hazard milestones comprise:

MCEER report documenting the Qualitative and Quantitative 2D and 3D Characterization of Post-tsunami Damage Using Very High-resolution Optical Satellite Imagery, Summer 2006.

MCEER report documenting the Qualitative and Quantitative 2D and 3D Characterization of Hurricane Damage Using Very High-resolution Optical Satellite Imagery, Summer 2006.

Journal article discussing Multi-hazard Damage Assessment Using Very High-resolution Optical Satellite Imagery Summer 2006.

Position paper on alternative strategies to transition MCEER into multi-hazard research in the area of remote sensing.

Workshop presentation at the 4th International Workshop on the Use of Remote Sensing for Post-disaster Response and Recovery. Summer 2006.