Performance Enhancement
of the Automated Concrete Evaluation System (ACES)

Federal Manufacturing & Technologies

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Final Report/CRADA Project Accomplishments Summary

CRADA Number 00KCP1087

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Date: 11/30/2001

Revision:

A. Parties

The project is a relationship between

Honeywell FM&T

2000 E 95th Street

PO Box 419159

Kansas City, MO 64141-6159

and

Missouri Highway and Transportation Commission

1617 Missouri Blvd., P.O. Box 270

Jefferson City, Missouri 65102

B. Background

The Missouri Highway and Transportation (MoDOT) Commission conducts an analysis of prepared samples of hardened portland cement concrete to determine microscopical properties. MoDOT contacted Honeywell International Inc. to develop an automated computerized image analysis system. Missouri Department of Transportation and Honeywell International Inc., under CRADA 98KCP1069, have jointly developed this system. Prototype software to perform the image acquisition, analysis, and reporting has been developed. However, ongoing validations to baseline performance of the software against actual manually derived results provided data indicating that additional software developments were required to ensure that the results provided by the ACE System are consistent with those obtained manually.

C. Description

At the completion of the last CRADA, several areas of improvement were identified for further development of the ACE system. These included:

1. Additional validation testing
 - Match void distribution better
 - Verify performance of analysis code (time-consuming)
 - Verify H/L and edge correlation
1. Additional software modifications
 - Improve color/shape/profile segmentation approaches
 - Improve fusion and H/L, edge-to-edge correlation
1. New software development

- Eliminate merged voids and bright regions
- Mosaic processing (multiple images at once)
- Pathology detection and processing
- Develop technique to better discriminate aggregate from paste
- Develop technique to identify quartz sand

This current CRADA was established with limited funds such that all of the above tasks could not be performed. As a result, the following goals for this CRADA were established:

1. Modify existing ACES software to better match the manually derived void distribution,
2. Perform additional validation testing of the existing ACES software,
3. Verify performance of the rulebases for high/low magnification and edge correlation, and for the fusion of image analysis results,
4. Present briefing at a MoDOT-sponsored technology interchange meeting.

All these tasks were performed with the following results:

- Validated 500+ images
- Identified some performance problems, inaccuracies
- Designed and implemented improvements to Color, Shape, and Profile codes
- Verified rulebases for H/L correlation, edge-to-edge correlation, and fusion
- Designed and implemented watershed algorithm for merged objects
- Identified and corrected most image-scale voids
- Identified additional enhancements.

Specific enhancements that were made are detailed below:

- Color technique enhancements
 - Added a neural network for color classification
 - Made a number of additional modifications to process special cases and to improve error handling (for example, bright regions on left edges)
 - Added "momentum" to neural network classification results to reduce class fluctuations at boundaries of paste and voids
- Shape enhancements
 - Added a watershed algorithm to eliminate merged voids and bright regions
 - Reviewed and modified correlation functions
 - Fixed small problems with thresholding and segmentation
- Profile enhancements
 - Improved median filtering process
 - Removed 2D filtering of spurious lines - added complexity
 - Improved handling of images with no bright regions
 - Modified detection thresholds to handle voids with anomalous intensity profiles (partial)
- Rulebase enhancements

- Confirmed existing rulebase operation
- Did identify additional edge-to-edge correlation rule (not implemented)
- Identified several other potential fusion rules

An industry meeting was held in St. Louis in May of 2001 to educate the concrete industry and other interested State Departments of Transportation about the ACE system and its capabilities. This has resulted in the initiation of a pooled fund effort to begin in March of 2002 and led by MoDOT. This effort will extend the applicability of the ACE system to other types of concrete and will further enhance the recognition and classification capabilities of the ACE software.

In summary, the ACE system now incorporates the enhancements developed under this CRADA, and the overall performance of the system has been improved. A third CRADA has been initiated to lay the groundwork for the proposed pooled fund effort which will involve other State transportation departments and the concrete industry.

D. Expected Economic Impact

This improved process will save time and enhance the evaluation process for hardened portland concrete. The Missouri Department of Transportation will quickly realize a savings in the hardened portland concrete evaluation process. Other potential applications for this prototype system include:

- Scanning and evaluation services provided to other state highway departments,
- The evaluation of concrete properties for other local, state, and Federal agencies,
- The evaluation of concrete properties for the construction industry,
- Manufacture of multiple units of the prototype for individual use for all of the above-mentioned organizations.

E. Benefits to DOE

The image processing approaches and improved image processing capabilities developed on this CRADA are currently being applied in nondestructive evaluation processes in support of weapons surety. In particular, the software analysis approach developed under this CRADA and the previous CRADA is currently being used in an Enhanced Surveillance project for the characterization of high explosive degradation.

The prototype ACE system developed for MoDOT provides surface scanning and image capture capability, and can be used to identify and characterize small voids or defects in surfaces (down to 2-3 microns). The algorithms and capabilities developed in this CRADA, plus the enhanced detection resolution to micron levels, can be used to examine optical imagery and identify and characterize small surface defects and flaws in weapons components (electromechanical, microelectronic, and optical). These techniques can also be used to enhance the capabilities of similar tools being developed within the Enhanced Surveillance diagnostics program. Such projects include:

- Neutron Radiography and High Resolution X-ray Tomography. These projects are building inspection tools for the inspection of entire weapons assemblies. This requires the development of image analysis algorithms to resolve fine features (millimeter scale voids and *at least* 1-mil cracks) with the goal of early detection of potential defects resulting from corrosion, cracking, etc. This CRADA has developed such tools and, as such, represents a capability enhancement over the 1-mil

requirement.

- Pit Surface Characterization and Endoscopic Imaging and Optical Coherence Tomography. These projects require the examination and characterization of the surfaces of pits to quantify and document the conditions of the pits. No specific minimum resolution is stated for these projects, but the imaging and analysis techniques that have been developed in this CRADA will provide a resolution capability down to 2-3 microns.
- Ultrasonic Characterization of Assemblies. This project is developing ultrasonic technologies to assess the strengths of bonds in weapons components. The data generated by these techniques is image data, and image analysis and pattern recognition algorithms are required to detect and characterize flaws in the bonds. This CRADA has developed similar algorithms which may be able to enhance the detection and characterization of bond flaws.

FM&T will make this technology and analysis capabilities available to other DOE researchers working on the Enhanced Surveillance Program projects mentioned above (and others). The technology that has been developed on this CRADA with MoDOT has improved DOE's ability to perform core surveillance of the weapons stockpile and has provided FM&T personnel with enhanced knowledge and experience which can be used in developing and integrating similar systems for DOE Programs. Without this CRADA, these enhanced detection and characterization techniques would not be available to the Enhanced Surveillance Program to improve the resolution and capabilities of the above-described ESP diagnostic tools.

F. Industry Area

A variety of industries could benefit from the technology developed under this CRADA. These would include:

- Construction industry, for the evaluation of concrete quality for buildings and roadways.
- Software industry, through the modification and application of the software techniques developed under this CRADA for other imaging, surface profiling, and pattern recognition applications.
- Medical industry, through the modification of the prototype system for use with microscope slides, or the use of the developed imaging and recognition techniques for the analysis of medical imagery.
- Federal agencies to include the FAA (for quality analysis of concrete used for runways) and the DoD (evaluation of materials for hardened facilities).

G. Project Status

Modifications to the prototype ACE system were completed in January 2000. Additional system validation and software development is required, however, to ensure that the system provides evaluation results to within a satisfactory level of agreement with the MoDOT experts. However, the system hardware and software presently can be used as a baseline system to develop integrated analysis approaches for any of the other application areas or industries mentioned above.

H. Point of Contact for Project Information

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I. Company Size and Point of Contact

Missouri Department of Transportation

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J. Project Examples

The following items are provided as attachments to this PAS:

Attachment A - SOW for Pooled Fund Study to begin in March 2002

K. Technology Commercialization

At the present time, there is no immediate plan to commercialize the prototype system. Additional software validation and development are required before a final determination can be made as to the potential marketability of this system. However, an invention disclosure has been filed jointly by FM&T and MoDOT on the prototype system.

L. Release of Information

I have reviewed the attached Project Accomplishment Summary prepared by Honeywell FM&T and agree that the information about our CRADA may be released for external distribution.

Original signed by

Name: Patti Lemongelli

Organization:

Title: Research, Development and Technology Director / Research

1-23-2002

Date

Missouri Department of Transportation

Research, Development & Technology Division

1617 Missouri Blvd.

PO Box 270

Jefferson City, MO 65102-0270

Attachment A

Proposed Pooled Fund Study

Sponsor – Missouri Department of Transportation

PROBLEM TITLE

Advanced Research of an Image Analysis System for Hardened Concrete

PROBLEM STATEMENT

The determination of the microscopical properties, hence air-void system, in hardened concrete provides a valuable link to the durability and performance of that concrete. Because of this, knowledge of the

air-void structure in hardened concrete is a valuable tool for many. Current manual methods (ASTM C 457 linear-traverse or modified point-count) used to determine the air-void structure in hardened concrete are extremely time-consuming, tedious, and require highly skilled and experienced personnel. Automating the system would save both time and effort and would improve the consistency and repeatability of the operation and its results. Previous efforts have been put forth by many to develop an automated system as such, but not to the degree of accuracy needed and required by many for total confidence. As a result, many resort to the conventional, manual methods of evaluating hardened concrete.

Over the last couple of years, a cooperative effort between the Missouri Department of Transportation and Honeywell Federal Manufacturing & Technologies has made significant progress towards the development of an image analysis system with the degree of accuracy desired. Furthering this research, specifically on a national basis, would work towards the full development of a system having the capability of accurately determining the air-void structure in hardened concrete while addressing all inevitable conditions that can be encountered during hardened concrete analysis. Complete development of this system would enable implementation by many in the field of concrete materials, construction, and research.

RESEARCH OBJECTIVE

The objective of this proposed research is to improve and expand the detection and analysis capabilities of the automated, concrete evaluation (ACE) system. MoDOT and Honeywell jointly developed this system. The focus of this proposed research will be on the following:

- Coordination of concrete imaging efforts with other states,
- Validation and testing of the ACE system on a broad range of concrete samples,
- Identification and development of software and hardware enhancements.

These enhancements will meet the needs of diverse users in the field of concrete materials, construction, and research.

The prototype ACE system was developed under a Cooperative Research and Development Agreement between the MoDOT and the Department of Energy Kansas City Plant (operated by Honeywell). The ACE system currently provides a baseline capability to analyze a prepared sample of Portland cement concrete and to provide estimates of the microscopical properties of the concrete in accordance with the ASTM standard, C457. The ACE system uses a high precision, two-dimensional computer-controlled stage to move the concrete sample under a research grade microscope. The image acquisition system consists of a color CCD camera, a frame grabber for image capture, and a dual processor (450 Mhz) tower PC. Customized image processing and pattern recognition software has been developed to identify air voids and extract void characteristics. These characteristics are used to calculate the Portland cement concrete microscopical properties of interest. All these system components are linked via a graphical user interface which aids the operator in the image acquisition, analysis, and review processes. Figure 1 provides a visual overview of the prototype ACE system.

Figure 1. Hardware and data flow for automated scanning system

The prototype ACE system currently has the capability to automatically scan and acquire imagery of a concrete sample. The acquired imagery is stored on the analysis computer and processed after the image scan is complete. The image analysis and pattern recognition software designed for the prototype is capable of detecting features as small as 2 microns on a sample. The software identifies each detected feature, classifies it as void, paste, or aggregate, and stores the classification information. Following the analysis of all acquired imagery, reports are generated by the system which provide estimates of several microscopical properties of interest, along with other information about the concrete sample. This automated analysis process provides consistent results which have been found to be in general agreement with results obtained by the human expert, although a significant amount of system optimization and validation is needed to bring the system capability to a level of accuracy required for typical evaluation operations.

The proposed project will improve and broaden the applicability of the prototype ACE system. This will be accomplished through extensive validation and testing of the existing analysis software, and the development of new analysis software. Specific tasks to be completed include

-
- Coordinate development efforts with other agencies

Contacts with other organizations in the field of concrete material, construction, and research will be established early in this project to identify other efforts in concrete imaging research. Techniques that may enhance the operation and accuracy of the ACE system will be identified and evaluated. Appropriate teaming relationships will be established as necessary and will ensure that the enhanced ACE system will have the broadest range of applicability within the concrete industry.

- Validation of prototype ACE system

Testing of the ACE system on a large number of concrete samples is necessary to assess its potential performance. The prototype version of the ACE software was originally developed using scanned imagery from a relatively small number of concrete samples. This allowed the basic analysis methodology for concrete evaluation to be developed. In order to completely evaluate this methodology, a significant validation effort will be undertaken to quantify the performance of the prototype software. This will naturally lead to the identification of specific and beneficial improvements for the software. Additionally, to thoroughly test the potential applicability of the prototype to industry-wide applications, a broad range of representative concrete samples will be acquired from across the nation. Samples with different compositions will be used to validate the performance of the prototype to ensure the software is sufficiently robust to provide accurate analysis of samples, regardless of the specific composition or source. Deficiencies and limitations of the prototype software and/or hardware will be identified and reported.

-
- Develop additional software and hardware approaches to enhance ACE system operation

Implementation of new analysis techniques will be performed as the need is identified in the validation phase. Software techniques will be developed to address “pathologies” discovered in imagery, such as merged voids, cracks, filled voids, and debris. Potential improvements to the computing hardware will also be explored with the goal of enhancing the speed of the scanning and analysis processes. Higher speed processors, multiple processors, and high performance computing hardware options will be considered.

-
- Write final report

A final report will be submitted. This report will include a summary of work others have performed in the area of concrete evaluation. Results of the prototype validation effort will be presented along with performance metrics (comparison with manually derived results). The capabilities and limitations of the prototype system will be discussed, and recommendations for application of this technology to other concrete industry tasks will be presented.

RESEARCH BENEFITS

The development the ACE system, which would accurately determine the microscopical properties of hardened concrete, would serve as a significant benefit not only to highway agencies, but also to the general, highway construction industry. Implementation of such an automated system would save time and effort and would eliminate the need for highly skilled and trained personnel required of the current manual methods. The system would also provide accurate and repeatable results. The strong need for a system, as described, has been demonstrated by the past efforts and continued interest of those in the concrete industry to develop an accurate, automated system using image analysis techniques.

ESTIMATE COST AND RESEARCH PERIOD

The estimated funding for this project is \$500,000 for the tasks noted above. The research will require approximately 24 months to complete.