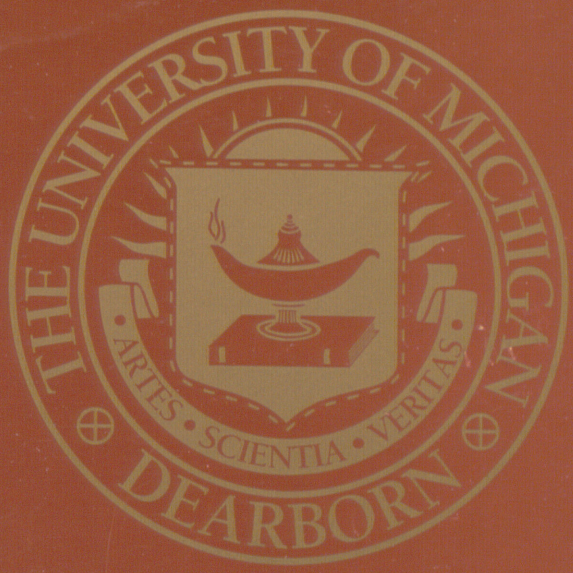


INDUSTRY/ UNIVERSITY COLLABORATION AT THE UNIVERSITY OF MICHIGAN-DEARBORN

A Focus on Relevant Technology

Sponsored by the
CENTER FOR ENGINEERING EDUCATION AND PRACTICE

Proceedings
June 18, 1997

University of Michigan-Dearborn

Preface

This volume summarizes the poster presentations of some research done by our faculty with industrial collaborators. This event is sponsored by the Center for Engineering Education and Practice (CEEP), which was created in 1992 to foster a clinical model for engineering education. The mission of the center is "to be a leader in incorporating engineering practice, design, innovation, and concepts of manufacturing technology at all levels of engineering education, by integrating the teaching environment with the world of practice."

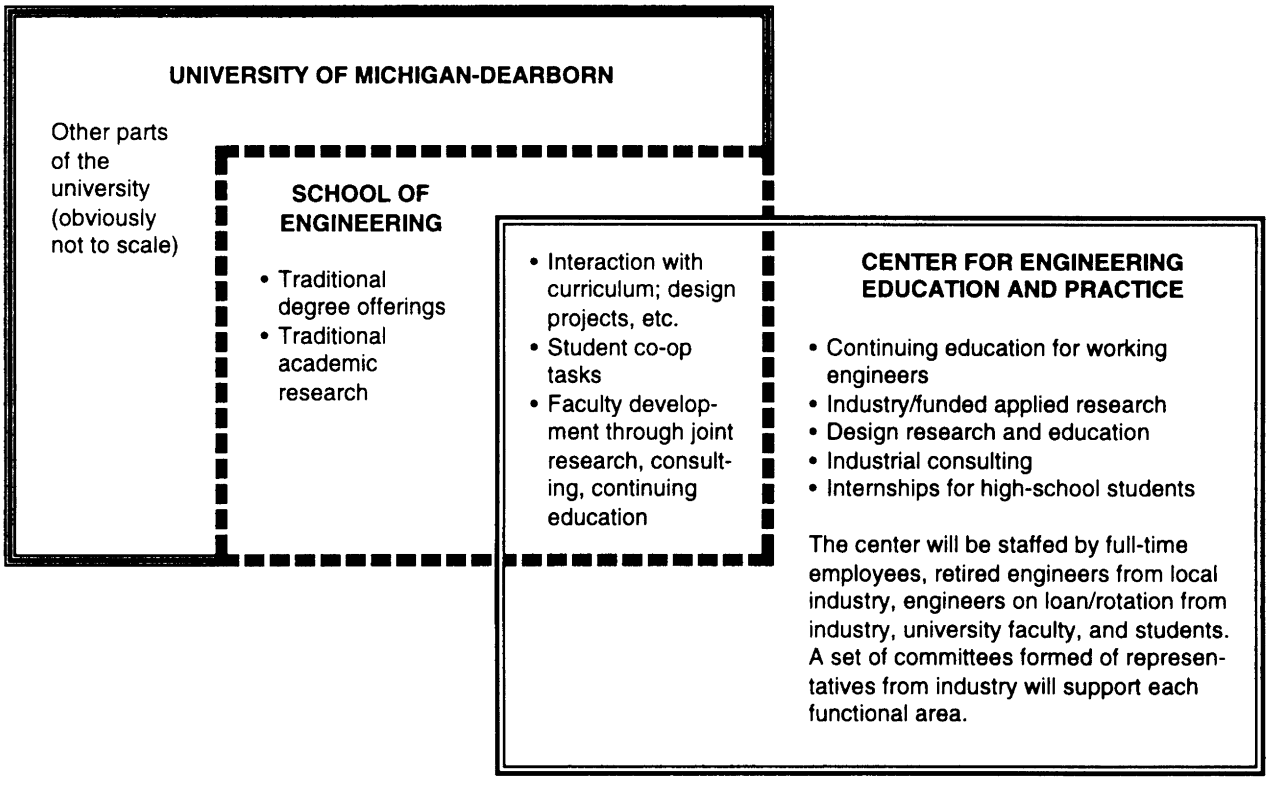
Since its inception, 60 projects have been funded, 95 individual collaborations have been supported, and 83 course changes have taken place.

The impact on our internal culture has been significant, to the point that today around 80% of our faculty have conducted collaborative research with industry. It has allowed an exchange of ideas in both directions and has added vitality to our curriculum that is truly remarkable.

This volume also serves as an invitation for industry to participate with us as we define new ways of incorporating ideas from practice into research and curriculum.

Subrata Sengupta
Director of CEEP
Dean, School of Engineering

A CLINICAL MODEL FOR ENGINEERING EDUCATION



Center for Engineering Education and Practice

School of Engineering
University of Michigan-Dearborn

Status as of June 1997
Outline of Accomplishments

The center was started in January 1992 with grants from Ford Motor Company and Chrysler Corporation, and the first set of projects was initiated in July 1992. Over $3,000,000 in support has been pledged from industry.

Projects

Five funding cycles (1992-1996) have supported over sixty projects. Summaries of those funded projects are available. A review meeting of sponsors and industrial collaborators with project directors is conducted every year.

Grants

Fourteen companies have made a total commitment of over $3,000,000; some for one year and others for five years. These companies are:

Acromag
Applied Intelligent Systems
Aries Technology
Craft Line, Inc.
Chrysler Corporation
Detroit Edison
Ford Motor Company
Michigan Bell Telephone (Ameritech Michigan)
Rockwell Automotive
Royal Design and Manufacturing
Sensormatic
Siemens Automotive
TRW
United Technologies Automotive

This is part of a $7,000,000 capital campaign to raise funds for the center and related laboratories.

Projects

The industrial organizations collaborating on the projects are:

Acromag
Allied Signal
Applied Intelligent Systems
ASC Incorporated
The Budd Company
CIMLINC
Cincinnati Milacron
Dana Corporation
Dearborn Group
Diesel Controls Ltd.
Dupont Automotive

Engineering Technology Associates
Ford Motor Company
General Motors Corporation
Hewlett-Packard
ICAD
Jabil Circuit, Inc.
Kodak
LTV Steel Company
Michigan Consolidated Gas Company
Monroe Auto Equipment
Motorola
Perceptron, Inc.
Preferred Technical Group
Royal Design and Manufacturing
Sandia National Laboratories
Siemens Automotive
United Technologies Automotive
TRW Financial Services, Inc.
US Army TACOM
William Beaumont Hospital
Wisdom Systems

Impact on Faculty, Students and Curriculum

The clinical model of engineering education advanced by the center envisions a collaborative atmosphere between practitioners, faculty and students that impacts research, curriculum, and teaching. The indices that measure these outcomes for the first five years are:

Number of projects:	60
Collaborating practitioners:	95
Faculty involved:	22
Number of undergraduate students:	34
Number of graduate students/research associates:	32
Number of high school students:	39
Number of new courses planned:	19
Number of times existing courses modified:	83

Facilities

The state has funded a 70,000-square-foot facility that houses the Center for Engineering Education and Practice, engineering laboratories and continuing education activities.

Assessment

Currently, a process of assessment has been initiated. Deliverables are being collated and outcomes analyzed. After the outcomes data is compiled and analyzed, individual interviews will be conducted with participants to assess the extent and volume of change and the possibility of replication.

Center for Engineering Education and Practice

(CEEP)

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Department of Computer and Information Science

REPORT BRIEF

Integrating Imaging Technology in Organizations

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Roberto R. Kampfner
Department of Computer and Information Science

PARTNERS: Conrad Foster
CEO Image Systems

BACKGROUND

CEO Image Systems is an organization that supplies imaging technology for document processing. Dr. Roberto R. Kampfner and Dr. Qiang Zhu of the CIS department, in a joint venture with Mr. Conrad Foster of CEO Image Systems, are conducting research on the use of imaging technology in organizations. Ms. Loretta Thiry of the CIS department is helping in the implementation of a pilot project in the CIS office.

OBJECTIVES

The objective of our presentation is to illustrate key aspects of this technology and its application in an organizational context. The overall idea is to enhance the function support capabilities of information systems with the help of the imaging technology provided by CEO Image Systems.

APPROACH

It involves using the function-support oriented approach to systems development in order to identify key requirements for the support organizational functions in a business, educational, or industrial environment and to show how information technology can be used to meet these requirements. A pilot project being developed applies CEO Image Systems' technology to the document processing in the CIS department office.

The integration of image information with other kinds of computer-based information and with the rest of the dynamics of organizational function is an important challenge associated with image processing systems. Our approach involves the development of implementation principles for this technology based on the function-support framework.

Function-Support as an Information Processing Paradigm

One basic idea is that information processing, to be effective, must be an integral part of function.

- In natural systems, for example, the information contained in the DNA guides the growth and development process using a biochemical (molecular) means of information processing. Molecular information processing is clearly integrated into the dynamics of biological function.
- In artificial systems, image processing systems make visual images available to computer-based information systems. This helps to integrate information processing mechanisms into the dynamics of organizational function.

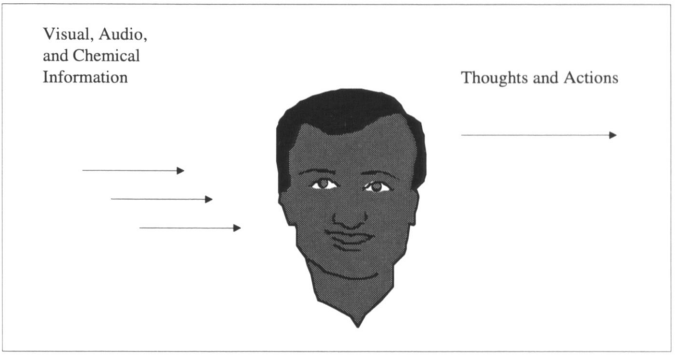


Figure 1. Information processing is integrated into the dynamics of function in natural systems.

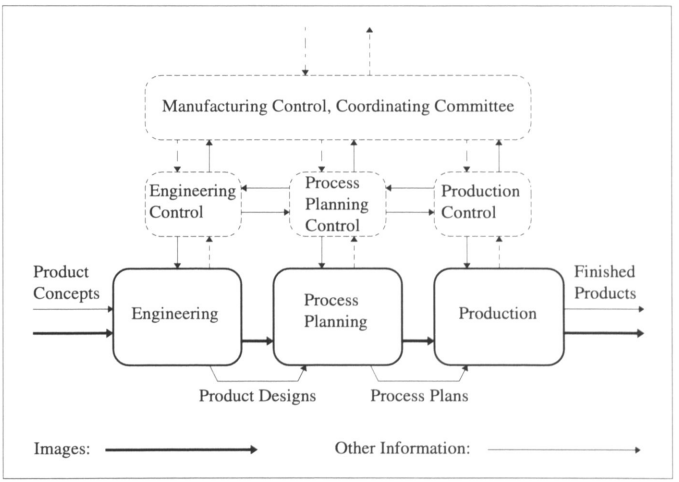


Figure 2. Information processing in organizations: Informational interactions between the engineering, process planning, and production units.

RESULTS

Expected results include the integration of image processing technology to the information system supporting the CIS department office and incorporation of the implementation principles developed for this technology into the methodology of information systems analysis and design.

CONCLUSIONS

The pilot project will help provide specific solutions to the integration of image processing technology in an academic environment. It will certainly shed light onto the solution of the general problem of integrating imaging technology in organizations. It will also help to tackle the challenge of integrating image processing technology into other computer-based information system applications and into the dynamics of organizational function.

IMPACT

This project stems from a vision shared by CEO Image Systems and the Department of Computer and Information Science of the University of Michigan-Dearborn. The idea is to provide a continuing model for research and collaboration on conceptual, technical, and methodological issues.

REPORT BRIEF

Supporting Collaborative Work Using Desktop Video on the Internet

June 18, 1997

MICROSOFT CORPORATION

SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

AUTHORS: Bruce R. Maxim and Kenneth L. Modesitt
Department of Computer and Information Science

PARTNERS: Educational Developer Curriculum Project
Microsoft Corporation

Conrad Foster
CEO Imaging

ASSISTANTS: Sangeeta Chatterjee
Graduate Student Research Assistant

Michael Wakenell
Undergraduate Research Assistant

BACKGROUND

Our students and faculty face demanding workloads, unforgiving deadlines, and the pressure of having to accomplish more with fewer resources. An important task for our campus is identifying technologies that can make distance learning a practical means of serving the lifelong educational needs of potential students. Much of the work done in industry requires the collaborative efforts of several people working effectively as a team. One of the challenges facing a commuting campus like ours is finding ways to support collaborative activities among students and faculty.

Imagine the impact on student learning if time and space barriers between members of the educational community were removed. Students could participate fully in collaborative study projects with each other and with their professors. They could access important lectures by experts from anywhere in the world and could contact their professors at times that are mutually convenient.

The Internet is readily available to many people in southeastern Michigan and can be used to support widely distributed educational activities. Desktop video conferencing and streaming video servers show great promise as means of providing cost-effective real-time interactive learning over great distances. Applications-sharing software can assist students needing to collaborate on course projects and can provide remote access to campus labora-tory facilities.

OBJECTIVES

One objective of this project is to test the feasibility of using low-cost desktop video technologies to support distributed, collaborative learning activities. A second objective of this project is to construct a laboratory that will allow the creation of web-based resources to support delivery of educational materials to students.

APPROACH

The intelligent redeployment of existing technology in innovative ways is at the heart of good engineering. Our approach is to build on the existing resources available to our students and faculty (namely, Windows '95, Pentium-class PCs, web browsers, sound cards, 28.8 modems and/or LAN connections). To complement this set of hardware, we allowed students and faculty to check out inexpensive microphones and Connectix parallel port cameras for home use.

To support video conferencing we deployed two CU-SeeMe reflectors on existing machines (one on Windows NT, one on Sun). Students were allowed to check out copies of the CU-SeeMe client software to use at home. To support streaming video we deployed a VDOLive server on an existing Windows NT machine (client software is free). To support applications sharing we made use of Microsoft's free Netmeeting program.

Our students and faculty are fairly proficient in both HTML and Perl programming on the web. The acquisition of additional web development software for the Hypermedia laboratory was funded by two Microsoft educational developer grants. These grants allowed us to acquire copies of several software development tools (MS Office 97, MS Access, Visual Basic, Visual C++, Visual J++, MS FrontPage, MS InterDev).

RESULTS

Students in several CIS courses produced high-quality web-based software projects this year. Many of these projects are posted on the CIS web pages (http://www.engin.umd.umich.edu/CIS), and some are on display in the Hypermedia laboratory. At least one course (CIS 350—Data Structures and Algorithm Analysis) has a complete set of course materials residing on the CIS web pages. Students in two courses, CIS 375 (Software Engineering) and CIS 495 (Design Seminar), made extensive use of CU-SeeMe and Netmeeting to do collaborative work with their design team members. The VDOLive server has become an integral part of the campus navigation project kiosk.

CONCLUSIONS

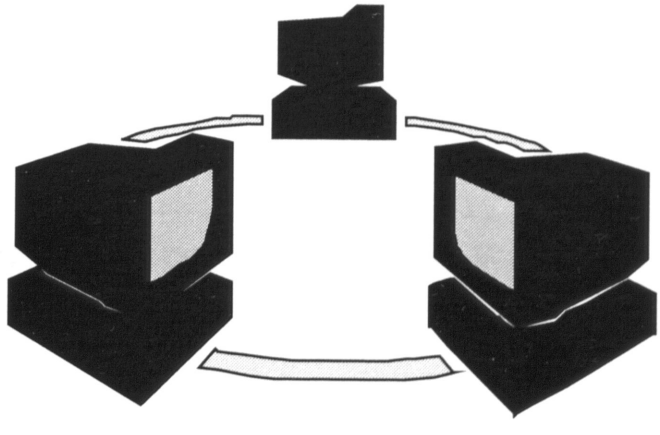
The resources acquired for this project provided many students with hands-on experience with both desktop video technology and web-based software development. Several students have been offered industrial positions involving one or both technologies this year. On the downside, it is still non-trivial to install desktop video for some students due to incompatibilities found in certain local Internet Service Providers. The university needs to expand the availability of MichNet into these areas. Providing desktop video equipment to faculty for home use is necessary to make this technology feasible as a means of extending office hours.

IMPACT

Video conferencing technology has the potential for widespread application in many disciplines on our campus and to many of our industrial partners. This project is relatively low risk; the cost per machine is only about $150. This technology has the potential of allowing students to spend less time commuting and more time learning. Telecommuting (common in industry) may become increasingly easier for professors. Remote site presentation of short courses also seems to be both technically possible and economically feasible.

ACKNOWLEDGMENTS

Chancellor Renick of the University of Michigan-Dearborn, Dean Sengupta of the School of Engineering, Microsoft Corporation, CEO Imaging, White Pine Software.



Department of Electrical and Computer Engineering

REPORT BRIEF

Continued Development of a Computer Based Speech Fluency Treatment Aid

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Selim S. Awad
Department of Electrical and Computer Engineering

PARTNER: Richard Merson
Electrical and Computer Engineering Department, William Beaumont Hospital

ASSISTANTS: Louis Przebienda, Mark W. Corless
Research Assistants

BACKGROUND

A computer software program to facilitate speech fluency rehabilitation has been improved. The program is an effective and inexpensive speech therapy tool for individuals with stuttering or other speech impairments. The software utilizes digital signal processing to analyze speech signals. This project is aimed at creating a computer treatment aid to motivate clients to practice by providing immediate visual feedback to the client's efforts and tracking client progress. The software package, Fluent v2.0 (see Figure 1.0), runs under Windows 3.1 or Windows 95 on an IBM compatible computer equipped with multimedia capabilities. Clients learn to alter their speech rate, loudness, duration, and onset in order to initiate and maintain speech fluency. Modifications have been made to the first revision of the software in order to improve graphics, scoring, and archiving of client attempts. There are plans to modify the software to aid in the rehabilitation of Parkinson clients.

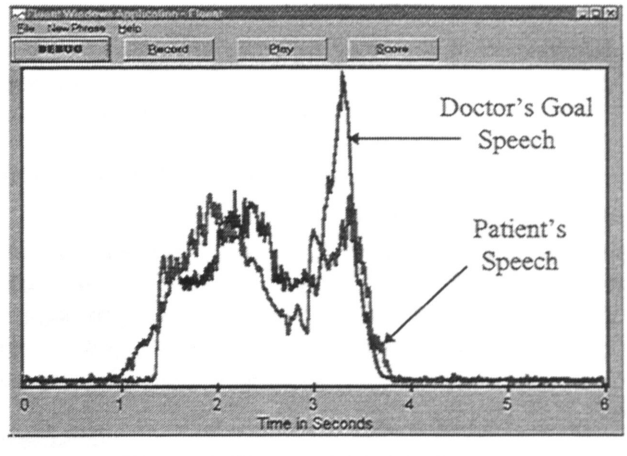


Figure 1. Fluent v2.0 Main Screen

OBJECTIVES

Stuttering is one of the serious problems focused on in speech pathology. It occurs in about one percent of the population and affects four times as many males as females. Studies support the hypothesis that stuttering is initially a neurological trait that may involve specific

abnormalities of speech motor control in the brain [1]. Stuttering cannot be permanently cured. It may go into remission for a time, or clients can learn to shape their speech into fluent speech with the appropriate speech pathology treatment. The most commonly utilized techniques for facilitating fluency are called *fluency shaping* and *stuttering modification* [2]. Both techniques involve shaping the tempo, loudness, effort, or duration of utterances. The clinician stresses the initiation and maintenance of a slowed speech sound onset with careful monitoring of speech volume and sound duration. Therapy is usually performed in a highly structured manner. It is critical for stutterers to be aware of the auditory perception of their own speech utterances.

APPROACH

The first step of therapy, for stutters of any age group, is to establish fluency in the client's speech. The clinician must initially teach speech fluency that can immediately be produced (through rate and rhythm changes) and perceived. The speech-language pathologist requests the client to initiate a speech pattern (i.e., syllables, words, phrases, or spontaneous speech). The client is asked to prolong the onset of a syllable, slow the tempo of the word utterance, or reduce the loudness or duration of a syllable or speech phrase. The client is encouraged to imitate or match the speech pattern of the clinician. The clinician gradually increases the difficulty of the speech utterance (i.e., rate, duration, tempo, speech sound complexity, or communication stress) over many treatment sessions.

RESULTS

Fluent v1.0 Software Overview

William Beaumont Hospital, Royal Oak, Michigan, and the Electrical and Computer Engineering Department at the University of Michigan-Dearborn formed a team to design an affordable speech stuttering therapy tool. The first result of this joint venture was a Visual C++-based software program, Fluent v1.0 [3]. The program plays a goal utterance (phrase) and displays an amplitude plot of the speech. The client may replay the goal several times to become familiar with the attributes of the phrase. When ready, the client repeats the phrase into a microphone. While speaking, the client's current amplitude is overlaid upon the goal utterance. This gives immediate feedback to the client's performance relative to the goal and allows the client to anticipate what amplitude or rate change is needed to reach the goal. Upon completion of the attempt, a score is assigned to each trial. The quantification of the effort allows the client to perceive how well he/she did.

This first version of Fluent was well received by clients at Beaumont Hospital. It became evident that improvements needed to be made to the software in order to ease usage by clients and to provide a more accurate scoring system.

Modifications Implemented in Fluent v2.0

Starting January of 1997, a graduate student (Mark W. Corless) in the Department of Electrical and Computer Engineering at the University of Michigan-Dearborn continued development of the Fluent software package. After gaining the required background to understand the programming language and structure used for Fluent v1.0, he put his efforts into modifying the existing code. These modifications included improving the graphics, scoring, and documenting the client's attempts.

Graphics Improvements

A startup screen was added with a field to enter the client's name as shown in Figure 2. This piece of data is used for storing to a file information about the client's attempts. There are also passwords that can be used to allow the doctor and software designer to enter different modes of operation. For example, a client does not have permission to alter prerecorded speech utterances, but the doctor must be allowed to record new phrases.

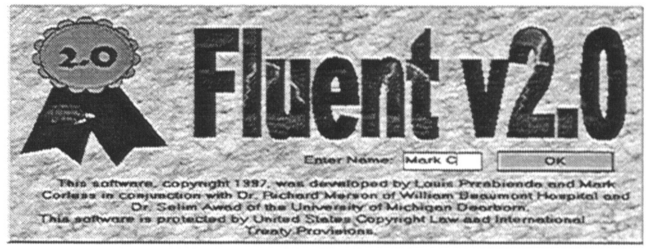


Figure 2. Fluent v2.0 Start-Up Screen

The major graphics improvement is the restructuring of the routines that display real-time information to the display. The new graphics allow the user to resize the screen and provide better sizing for high-resolution monitors. The new graphics implementation also allows easy display of debugging information for the scoring routines.

Scoring

The original version of Fluent processed the doctor and client speech signals, then compared the relative starting times, ending times, onset slope, duration, and maximum amplitudes. The major new contribution to the scoring was the introduction of a general shape comparison algorithm. The algorithm was originally designed using a different programming language (Matlab). This algorithm was converted to Visual C++, further optimized, and included in Fluent v2.0. The introduction of the new shape scoring algorithm also affected the previous scoring routines by allowing an optimization of those routines as well. The final result is a programming module that compares the doctor's speech to the client's speech and displays the score for each attempt in a dialog box as shown in Figure 3.

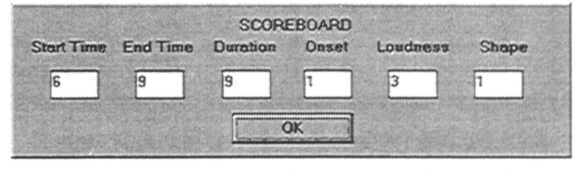
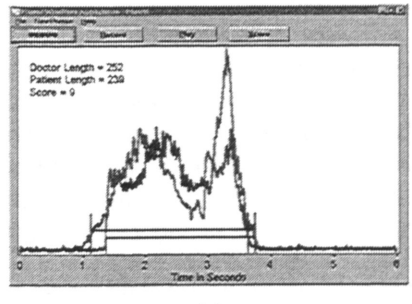
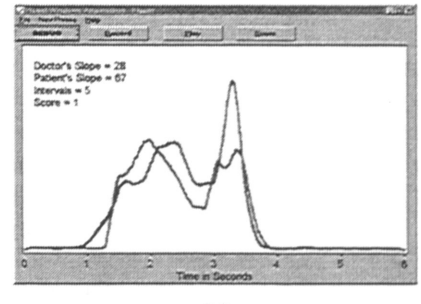


Figure 3. Fluent v2.0 Scoreboard Dialog Box

As an aid to the developer and clinician, several debugging modes were added to the software. A password-protected debugging mode allows for easy display of steps used while processing the signal. Examples of some scoring routines using debugging mode are shown in Figure 4.



(a)



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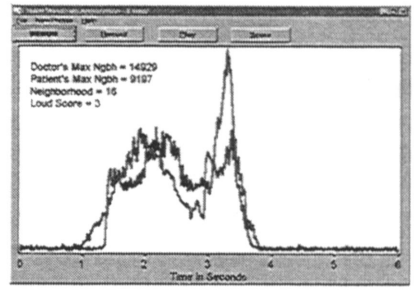
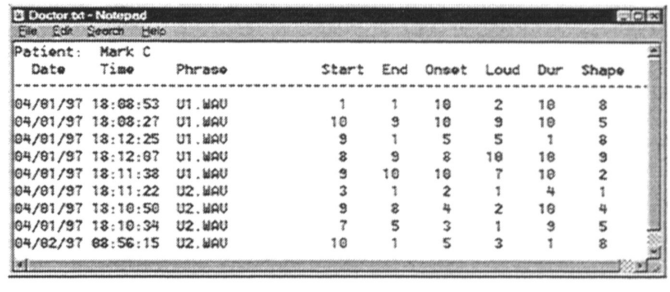


(c)

Figure 4. Debugging Screens for length of speech (a), onset slope (b), and maximum amplitude (c) scoring algorithms

Documenting Client Attempts

Although the ability to score client performance is the backbone of this program, it is important that these scores can be stored for future use. Fluent v2.0 has the ability to generate a history file summarizing client attempts (Figure 5). This information can be printed or imported into a spreadsheet program like Excel. The clinician can use this information to assess client progress and observe how much time clients spend practicing.


Doctor.txt - Notepad

File Edit Search Help

Patient: Mark C

Date	Time	Phrase	Start	End	Onset	Loud	Dur	Shape
04/01/97	18:08:53	U1.WAV	1	1	10	2	10	8
04/01/97	18:08:27	U1.WAV	10	9	10	9	10	5
04/01/97	18:12:25	U1.WAV	9	1	5	5	1	8
04/01/97	18:12:07	U1.WAV	8	9	8	10	10	9
04/01/97	18:11:38	U1.WAV	9	10	10	7	10	2
04/01/97	18:11:22	U2.WAV	3	1	2	1	4	1
04/01/97	18:10:50	U2.WAV	9	8	4	2	10	4
04/01/97	18:10:34	U2.WAV	7	5	3	1	9	5
04/02/97	08:56:15	U2.WAV	10	1	5	3	1	8

Figure 5. Archive File Created by Fluent v2.0

CONCLUSIONS

The major downfall of many treatment programs is that clients are not motivated to carry over the practice of treatment methods into their daily life. Unless the clinician is present, many clients neglect their practice. The immediate next step in the evolution of this software is to allow clients to take the program home and bring back the archived results for the clinician to assess. Animations are currently being developed to display on the scoreboard to give clients an immediate reward for their efforts.

Funding is being sought to modify the Fluent software to assist in the treatment of Parkinson's disease clients. Three-quarters of Parkinson's disease clients have a voice disorder, yet only a small number (around four percent) receive speech treatment. Recently, clinical research has documented positive clinical outcomes using highly structured voice amplitude strategies for Parkinson clients [4]. The techniques for scoring and grading these strategies is very similar to those used for stutterers.

The original Fluent software has been improved to be more accurate and user friendly. The graphics capabilities have been increased, and the scoring routines have been optimized and more thoroughly tested than in the previous version. Fluent v2.0 is currently being tested clinically at the Speech Pathology Center of William Beaumont Hospital, where it has been well received. There are plans to install this software in some clients' homes. Home installation of the software will provide a true test of the system and make full use of the archiving capabilities.

IMPACT

The project will have impact on undergraduate and graduate education through student involvement and other means. Currently, there is one undergraduate and one graduate student involved in the project. Also, some courses will be enhanced by the project, including ECE 584 (speech processing), ECE 580 (digital signal processing), ECE 480 (introduction to digital signal processing), ECE 431, ECE 432, and ECE 491. The course enhancement will be in the form of introducing new concepts regarding the use of speech processing to aid speech pathology. Also, the project can generate software that will be commercially marketed to thousands of stuttering patients.

REFERENCES

[1] S. Jacqueline, "Speaking Easy: for kids who stutter, early treatment can make the words flow smoothly," *Health*, NY, 23:38-9, April 1991.

[2] *Stuttering: An Integration of Contemporary Therapy*, Stuttering Foundation of America, Publication No. 16, 1993.

[3] L. Prezbienda, *Speech Stuttering Therapy with the Computer*, master's thesis for ECE 699, University of Michigan-Dearborn, Department of Electrical and Computer Engineering, 1996.

[4] L. Ramig, "Speech Treatment for Individuals with Parkinson Disease," Special Interests Divisions, *Neurophysiology and Neurogenic Speech and Language Disorders* 3(5), 15-18.

REPORT BRIEF

MOSFET: The Michigan Off-road Sensor Fusing Experimental Testbed

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Sridhar Lakshmanan
Department of Electrical and Computer Engineering

PARTNER: Paul Lescoe
US Army Tank Automotive Command

ASSISTANTS: Michel Beauvais, Randy DeFauw, Chris Kreucher, Michael Moore
Research Assistants

BACKGROUND

MOSFET (the Michigan Off-road Sensor Fusing Experimental Testbed) is a vehicle designed to autonomously navigate a course replete with obstacles, lanes, and other common road challenges.

Currently, the system utilizes a golfcart chassis and employs one forward-looking camera, two side-looking cameras, and a bank of ultrasonic sensors to survey its surroundings. MOSFET uses these sensors to develop a model of the world around it (called a worldmap) and to decide what actions it should take to successfully navigate the terrain.

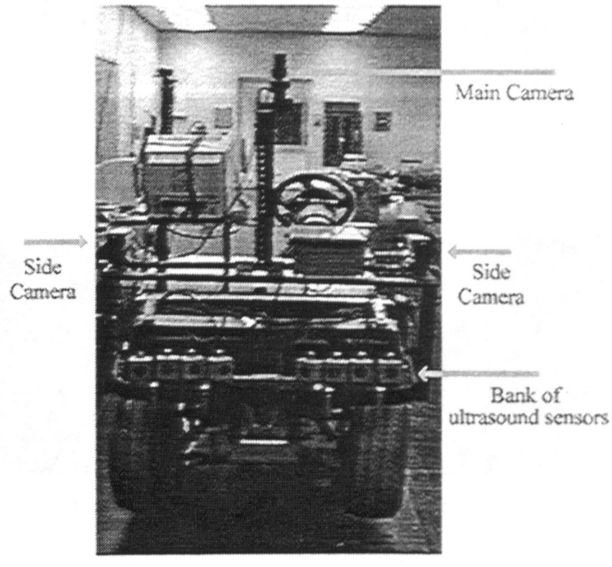


Figure 1: MOSFET

OBJECTIVES

MOSFET is entered to compete in this year's International Ground Robotics Competition. Vehicles from across the United States will each try to successfully navigate a course that is ridden with obstacles and lane markings. The rules of the course dictate that the path will be grass, blacktop, asphalt, or any combination. Furthermore, lanes will be white or yellow

and may be either striped or dashed. Obstacles will be placed at random locations both on and off the track. The vehicle that completes the course in the shortest amount of time while avoiding obstacles and remaining within the lane markers will be declared the winner.

APPROACH

MOSFET uses images from the two side-looking cameras to detect lane obstacles, and it uses a variety of color segmentation techniques to find yellow or white lane markers on grass or pavement in a variety of lighting and weather conditions. Three sample images are shown below, with the detected lanes marked with black stripes.

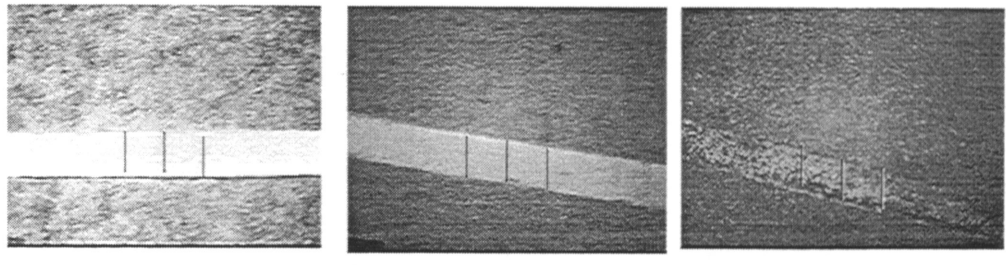


Figure 2: Lane-finding results

MOSFET next uses the main camera image to determine the location of obstacles in its path, based on color. Currently, the known obstacle colors include red, white, and yellow. The following figures are examples of these three colors as detected by the color transformation and segmentation algorithms.

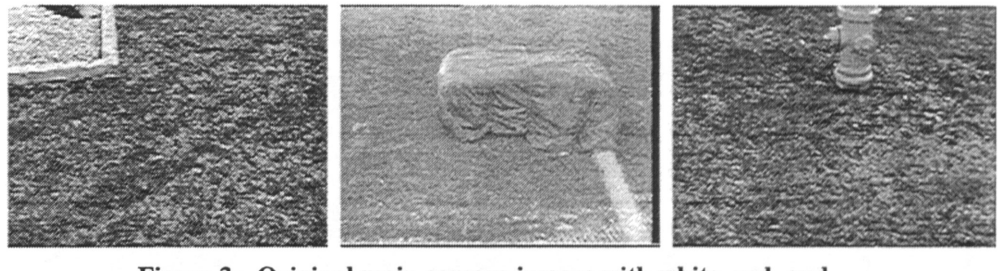


Figure 3: Original main camera images with white, red, and yellow obstacles respectively

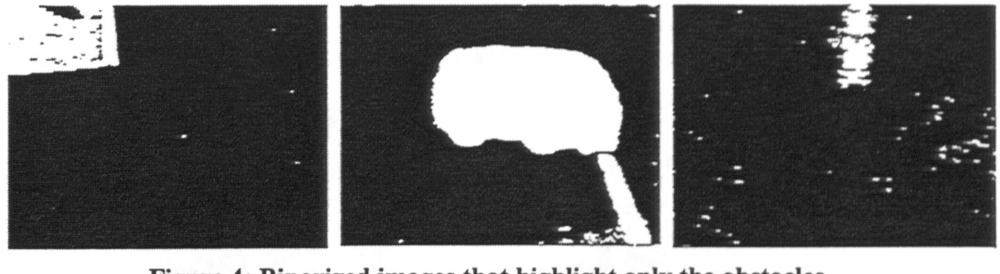


Figure 4: Binarized images that highlight only the obstacles

Once the camera data have been acquired, MOSFET creates a navigational worldmap by combining information received from its various systems. First, MOSFET takes the main camera obstacle information and projects it onto a grid map representing the area in front of the vehicle. Next, MOSFET takes the information from the side-looking camera and uses it to find the lanes in front of the vehicle. MOSFET next correlates the sonar information with the main camera obstacle information. Finally, MOSFET fuses all of this information into one navigation map.

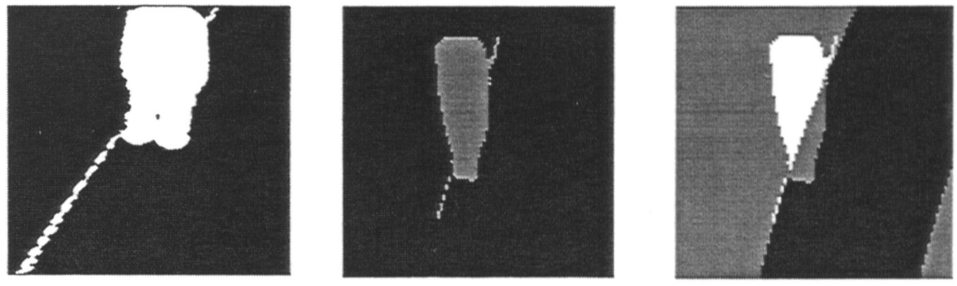


Figure 5 (L to R): Main camera obstacle image; projection onto grid map; lane information added

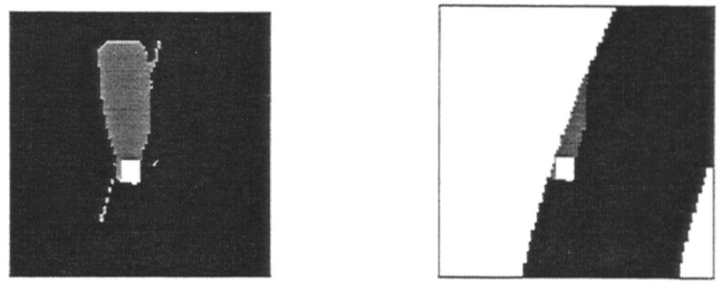


Figure 6 (L to R): Sonar information correlated; final navigation map

RESULTS

Figures 7 and 8 show a sample data set generated from one iteration of MOSFET. First, the three camera images are acquired:

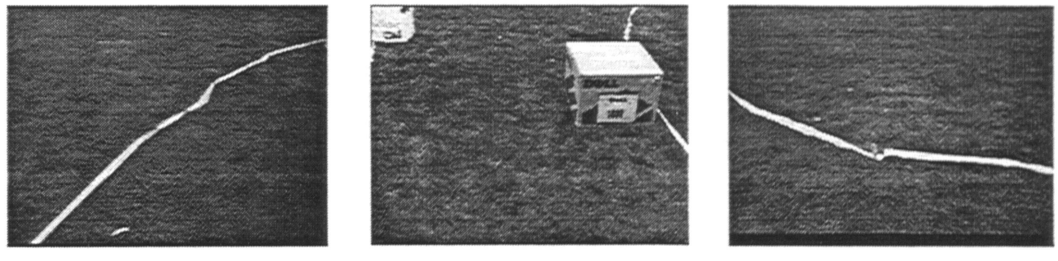


Figure 7: A sample data set

Next, the data acquired are processed according to the algorithms described earlier. Finally, as is shown in Figure 8, the optimal steering angle for the present situation is chosen.

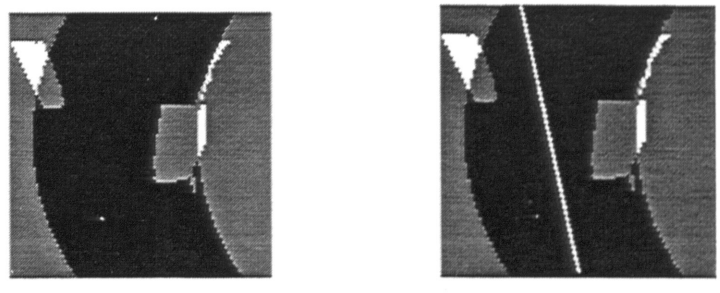


Figure 8 (L to R): The navigation map and the final steering angle chosen (drawn in white)

CONCLUSIONS

MOSFET is an autonomous vehicle developed for the purpose of navigating a previously unknown course. During this navigation, both obstacles and lane markings must be recog-

nized and avoided. This recognition is performed using three main sensors, namely, a forward-looking camera, a set of side-looking cameras, and a bank of ultrasonic sensors. Information from each of these sensors is processed individually to generate necessary data. Finally, all of the information is fused together to create an accurate picture of the world surrounding the vehicle. This worldmap is then used to determine the optimal steering angle of the vehicle.

ACKNOWLEDGMENT

The members of team MOSFET wish to thank the following people and organizations for their contributions to the success of the project:

- Professor Natarajan Narasimhamurthi for assistance provided in developing the color transformation algorithms as well as general guidance given in the development of the project
- Professor John Miller for aid with respect to sensor data acquisition and processing, as well as help with image processing and filtering techniques
- Professor Eric Ratts, for assistance with creating a cooling system
- Professor Yi Zhang, for assistance with developing the steering system gearing
- The National Science Foundation (NSF) for summer student support

REPORT BRIEF

In-Process Measurement System for Automotive Parts

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Department: Electrical and Computer Engineering

PARTNERS: Jack Dawson and Charles Marlette
Preferred Technical Group

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Research Assistant

BACKGROUND A manufacturer of automotive parts wished to integrate machine vision technology into its manufacturing processes to improve product quality and reduce costs.

OBJECTIVE The development of a low-cost in-process gauging system was the primary objective of the project. For one type of part, a power steering connector, measurements on a groove are desired. The depth and width of the groove, and the distance between the start of the groove and the end of the power steering line are gauged. For the second type of part, a crimped connector attached to a brake hose, the measurements of interest are the two diameters of the crimp and the bell length. Since the system is intended for production use, it must be reliable and have a user interface suitable for plant personnel.

APPROACH In order to gauge both parts, a video camera was used to acquire a back-illuminated image or silhouette of the part. The video image was then digitized with a frame grabber and stored in computer memory. The digitized image was processed so that key features in the image could be identified, and the distance in pixels between these features calculated and converted to inches with a calibration factor.

The basic hardware to accomplish the gauging tasks consists of a standard video camera, light source, frame grabber and an industrial personal computer. In order to minimize hardware costs, a standard 50mm C-mount camera lens and extension tube were used with the video camera. Consideration had been made to use more expensive telecentric optics so that parts placement would not cause a change in magnification with a resulting loss of accuracy. With the 50 mm lens, however, magnification effects were lessened due to the greater standoff distance between camera and part. Since relatively repeatable parts placement is anticipated, this was a satisfactory cost/performance tradeoff.

For image acquisition, a low-cost PCI-bus frame grabber-card was chosen. With this type of card, video capture can occur at up to 30 frames/second due to the very wide bandwidth of the PCI-bus. With a Pentium CPU, very rapid image analysis can be performed so that every part can be gauged without slowing down production rates. In fact, gauging speed exceeds production rates by a significant factor so that a single computer and frame grabber can handle several different applications simultaneously. A camera multiplexer can access

data from each camera for different measurements. Software to provide this additional functionality is currently being developed and will further reduce the hardware costs on a per-measurement basis.

In order to interface the gauging system to production equipment, a digital control card has been provided. This card has optically isolated inputs and relays to provide high isolation with plant programmable logic controllers or similar hardware. When a part is in place and ready to be measured, a voltage will be applied to one of the card inputs. An image will be acquired and analyzed and one of two relays will be energized to indicate if the part is to be accepted or rejected.

A typical acquired image of a back-illuminated part with a groove is given in Fig. 1. This particular part is used in power steering assemblies and the dimensions of the groove are critical. A gasket is placed in the groove to prevent leakage of power steering fluid. The measurements of interest are illustrated in Fig. 2.

A typical image of a crimped brake-hose connector is shown in Fig. 3. The hose is visible on the left side of the image where it is inserted into the fitting. The measurements of interest, the two crimp diameters and the bell length, are illustrated in Fig. 4.

In order to provide the measurements described here, analysis software was written in the C language. A special compensation algorithm was implemented for anticipated illumination variations that are likely to occur over time. By calculating the histogram for each newly captured image, a threshold can be determined that will provide consistent gauging results regardless of light level.

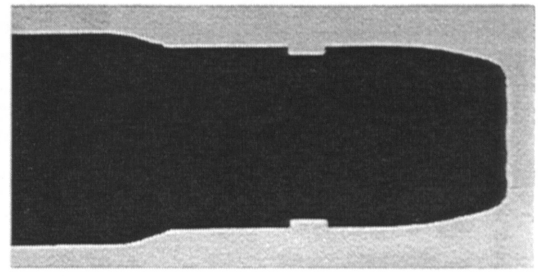

Figure 1. Back-illuminated part with groove.

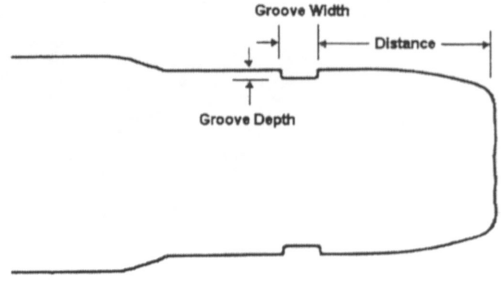

Figure 2. Groove dimensions to be gauged.

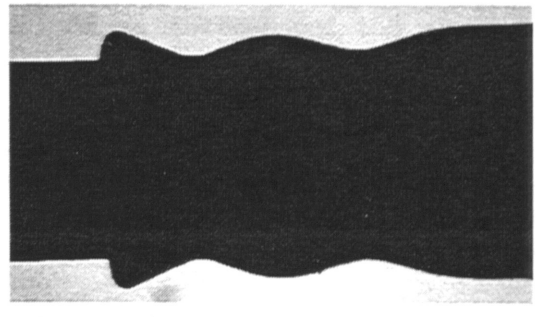

Figure 3. Typical image of crimped part.

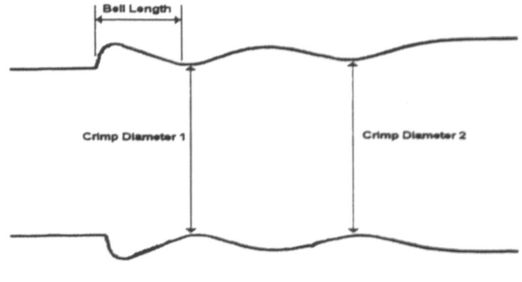

Figure 4. Crimp measurements

Other routines use the calculated threshold to detect the image edges and identify the features associated with the desired measurements. Compensation is also provided for part rotation by determining the angle of the part relative to the horizontal axis of the camera.

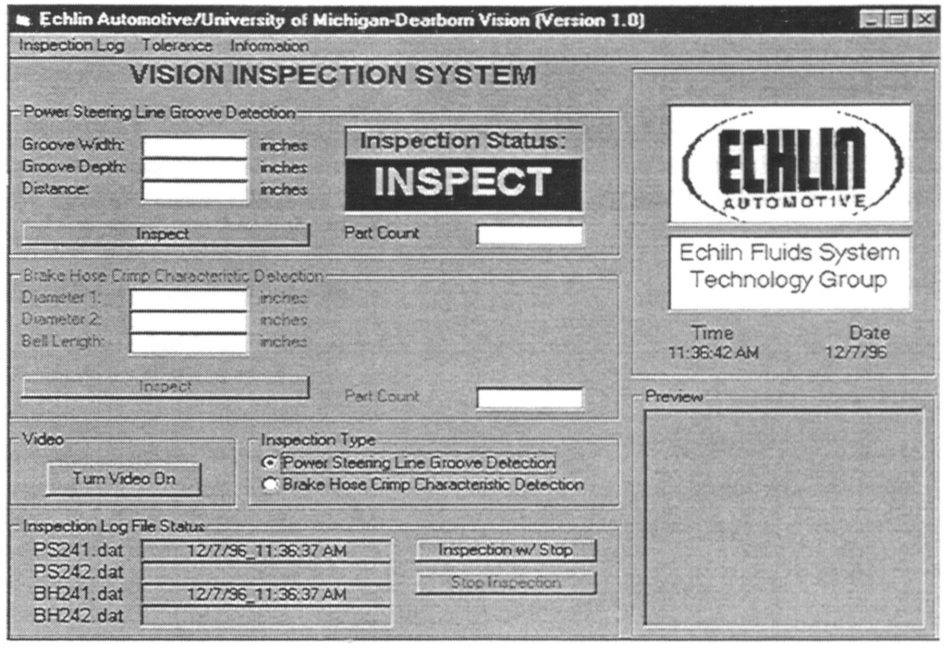

Figure 5. Vision System Graphics User Interface

Pixel locations are then transformed to remove the rotation. Such transformations can require significant amounts of time, but use of a special lookup table minimizes the time.

A graphical user interface was designed to control the image acquisition and processing routines and display the results to the user as well as record the results to a separate inspection log for the power steering line and brake hose inspections. This interface is shown in Figure 5.

There are separate frames for the inspection of the two component types, the selection of which is chosen using the radio buttons in the "Inspection Type" frame. There are two modes for each inspection. The first mode is the manual mode for setup and testing purposes. In this mode, the user presses the "Inspect" button and a single inspection is performed. The second mode is used for production gauging and an inspection will occur whenever a "part-in-place" signal is received.

RESULTS

The vision system has been undergoing evaluation and appears to meet production requirements. Measurement accuracy is .002", which meets the original goal of the project. Plant installation should occur sometime this summer.

IMPACT

Undergraduate student participation in the development of an advanced measurement system has provided significant benefits for the students and faculty involved, and the corporate partner. Important benefits include:

- *Excellent experience for participating students*

The students acquired a variety of new skills including software and integration, design of user interfaces, minimization of degradation associated with noise and nonlinear system elements, and robust coding techniques that can handle a wide variety of unusual conditions such as misplaced parts, poor illumination, and the presence of dust and dirt when an image is captured.

♦ *Case studies for graduate and undergraduate courses*

This project has already been used to demonstrate a number of important machine vision concepts in several courses. The basic system has been used as a case study in ECE588, Applied Machine Vision, and will also be presented in the new undergraduate vision course ECE588, Introduction to Machine Vision.

♦ *Benefits for the corporate partner*

A vision system has been developed for production use and should result in improved product quality and lower production costs.

REPORT BRIEF

A Fuzzy System for Automotive Fault Diagnosis

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Electrical and Computer Engineering

PARTNER: Brennan Hamilton
Ford Motor Company

ASSISTANT: Tie Qi Chen
Research Assistant

BACKGROUND

Diagnosis of impending or actual faults through operating data or observed characteristics of a dynamic system is generally performed by specialists who are trained in the interpretation of such patterns. The existing techniques in engineering diagnosis are largely dependent on the individual engineers' experience. This project attempts to solve automotive engineering diagnosis in the application of the end-of-line test used in assembly plants.

The major US automotive companies have launched an end-of-line test system at every North American assembly plant. In order to accomplish this task, a system is designed to collect and analyze electronic engine controller (EEC) data while the vehicle is dynamically tested. Operators drive the vehicles through a preset profile and the vehicles are either passed or failed according to the data collected during the test. The decision is made based on two information sources, the EEC on-board test and an off-board test performed by the vehicle test system on EEC-generated data. This project focuses on solving the second problem. There is a strong need to develop an intelligent system capable of **prompt and reliable diagnosis** for the end-of-line vehicle test. The system we discuss here uses exclusively the data currently available at the test sites.

OBJECTIVES

The **objective** of this project is to **advance the current technology** in engineering diagnosis. This objective is attained through the development of an intelligent fuzzy diagnostic system for the end-of-line vehicle test in assembly plants.

APPROACH

We have developed a fuzzy model (see Figure 1) to solve the engineering diagnostic problem. The fuzzy diagnostic model consists of a knowledge base and an inference engine. The knowledge base contains a set of fuzzy rules and fuzzy membership functions. The fuzzy knowledge rules are generated by engineering heuristic knowledge or by machine learning algorithms on training data. The fuzzy rules are completely characterized by a set of control variables, $X = \{x_1, x_y, ..., x_n\}$. Each control variable is associated with a set of fuzzy terms $\Sigma_i = \left\{\alpha_i^1, \ldots, \alpha_i^{p_i}\right\}$. The control variables are the parameters that reflect the faulty behavior that the system is responsible for detecting. Therefore the fuzzy model has one solution variable y, which describes the particular type of fault that the system is responsible for detecting. Solution variable y is associated with fuzzy terms $\Gamma = \{\tau_1, \ldots, \tau_q\}$. For example, a vacuum leak diagnostic system can have 5 control variables (Throttle_Position, Lambse_1,

Lambse_2, Idle_Speed_DC, Mass_Air_Flow) and one solution variable (Vacuum_Leak). Each fuzzy rule has the format:

IF (x_{k1} is α_i^{k1}) AND (x_{k2} is α_i^{k2}) AND ... (x_{km} is α_i^{km}), **THEN** y is τ_j

where $m \leq n$, $\{x_{k1}, x_{k2}, ..., x_{km}\} \subset X$, $\{ \alpha_i^{k1}, \alpha_i^{k2}, \ldots \alpha_i^{km} \} \subset \Sigma_i$, $\tau_j \in \Gamma$.

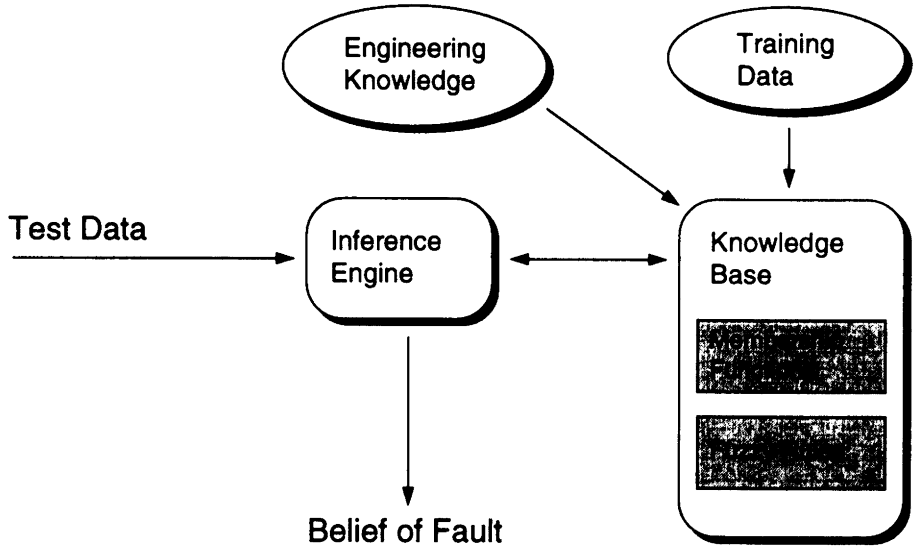

Figure 1. A fuzzy model for engineering diagnosis.

The degree to which the fuzzy action is taken depends on the degree of truth in the antecedent proposition. Within this application domain, unconditional rules are not necessary. Unlike conventional expert systems where statements are executed serially, fuzzy logic is a parallel processing paradigm in which all the rules are fired; however, some rules may have no degree of truth in their premise and therefore fail to contribute to the outcome. There are two types of fuzzy knowledge. First, for each type of fault y, the automotive engineers will provide an initial set of rules. This set of rules is concise and supports the functional mechanics of the fuzzy model. The membership functions are initialized based on this set of rules. In order to be feasible for fuzzy systems exhibiting intelligent behavior in solving complicated problems, it is important to develop mechanisms for automating the processes of knowledge acquisition and maintenance. We have developed fuzzy learning algorithms that automatically generate fuzzy rules and optimize fuzzy membership functions. The fuzzy rules are generated using a clustering method. A stochastic annealing method was used to optimize membership functions. Our system currently supports six types of MBFs, namely, linear, triangular, sigmoid, β-curve, Gaussian, and squared sine.

At the test stage, the fuzzy system reads a test data sample, and the fuzzy inference engine applies rules in its fuzzy knowledge base to the sample data and then generates the degree of belief whether the vehicle represented by the sample data has the particular type of fault.

The fuzzy model has been implemented in the programming language C on PCs. The system currently was designed for the end-of-line test in automobile assembly plants. The implemented system has been tested on large data sets of different vehicle models downloaded directly from the Ford assembly plants, and the test results show that the system is both robust and accurate.

RESULTS

We have implemented the fuzzy diagnostic model to detect vacuum leaks in the electronic engine controller (EEC). We tested the system on two different types of vehicle models, the Ford Thunderbird '95 and '96 models and the Ford Lincoln Towncar. The fuzzy learning program generated 18 fuzzy rules for the Thunderbird model and 23 fuzzy rules for the Lincoln Towncar. We tested the fuzzy diagnostic system on data sets of over 10,000 samples of both vehicle models, and the accuracy of the system was above 99 percent.

As a result of this project, we received a grant from the National Science Foundation to support a project titled "A Distributed Fuzzy System Model for Automotive Diagnosis." The duration of the project is two years and the award is in the amount of $93,450. We have also received funding from the Ford Motor Company in the amount of $40,000 for a period of two years.

A number of publications have been generated from this project:

- Yi Lu, Tie Qi Chen, Brennan Hamilton, "A Fuzzy System for Vacuum Leak Diagnosis," NSF Design and Manufacturing Grantees Conference, Seattle, Washington, 1997.
- Yi Lu, "A Self-Learning Fuzzy System for Automotive Fault Diagnosis," the Ninth International Conference on Industrial and Engineering Applications of Artificial Intelligence amd Expert Systems, Japan, pp. 167–172, June 1996.
- Brennan T. Hamilton and Yi Lu, "Diagnosis of Automobile Failures Using Fuzzy Logic," the Eighth International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Melbourne, Australia, June 5–9, 1995.

CONCLUSIONS

We have developed and implemented a fuzzy model for automotive fault diagnosis. The fuzzy model has two modes, learning and detection. Within the learning mode, a new rule generation method and a membership function optimization method are used. The model has been implemented into a fuzzy diagnostic system that detects the vacuum leak in the electronic engine controller in automobiles. The fuzzy vacuum leak diagnostic system has been tested on two different vehicle models, the Thunderbird and the Lincoln Towncar. The testing results show that the system is effective, fast, and compact, suitable for running on a PC platform. Currently, the system is in the process of being transferred into Ford Motor Company's diagnostic systems.

IMPACT

Educational impact: A course based on this project, "Fuzzy Diagnosis in Automotive Engineering," was offered to Ford engineers in May 1996. There were 20 participants in this course. The results of this project are also used in senior student project design and in graduate courses, including ECE 579 Intelligent Systems and ECE 580 Neural Networks.

Industrial impact: The results of this project are currently being transferred to a Ford diagnostic program to be used in Ford assembly plants.

REPORT BRIEF

Machine Vision Inspection of VF Display Boards

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Electrical and Computer Engineering

PARTNER: Anthony Tisler
Jabil Circuit, Inc.

ASSISTANT: Tie Qi Chen
Research Assistant

BACKGROUND

Vacuum fluorescent (VF) display boards are widely used in the automobile industry to display information about vehicles' status. The displays are illuminated by circuit boards specially designed to disclose specific information including speed, mileage, fuel level, compass heading, etc. These displays are the only part of the circuit board seen by the automobile operator, and therefore high quality of display is required to ensure an excellent report from the customers. Once the circuit board is complete, the entire board must be tested for proper function. VF inspection is the inspection of various display patterns of each VS board in production. VF displays are mounted directly onto the circuit board using pin-through-hole and surface mounting. In current manufacturing, the screen test of a VF display is visually inspected by a functional test operator. The functional test forces the display to show pre-specified patterns, which are verified by the test operator. The functional test lasts about four to eight seconds per circuit board, and in that time an operator is expected to inspect at least two display patterns of the VF board. Two major problems related to manual inspection are:

- Currently, because of time limits, an operator can inspect only two display modes, which is not enough to ensure that the display board is functionally good. Ideally, every possible display pattern should be inspected. However, the number of display combinations that can be inspected is bounded by how fast a human can inspect them.
- The nature of the visual inspection is repetitive and tedious. It is impossible to expect a person to maintain peak awareness during an eight-hour period.

The VF display functions similarly to most calculator displays. Different boards have different display contents. Figure 1 shows the image of an electronic compass/temperature/trip board used in one type of automobile. The entire display of a VF board consists of a number of **fields**. Each field is composed of **segments**. A group of components whose state is independent of other components is called a **segment**. Each segment in the board can be in one of two states: *on* or *off*. The display in Figure 1 has 18 fields; for illustration purposes, each is bounded by a rectangular box. A field can have more than one segment. For example, the fields "0" and "8" in this image have multiple segments. A field is called a **single field** if it has only one segment, i.e., if all the components within the field always are in the same state, either all *on* or all *off*. Figure 2 shows all the single fields of the display board in Figure 1. Although some single fields have multiple letters, all the letters in the same single field are controlled by one external pin; therefore, the letters are always in the same state.

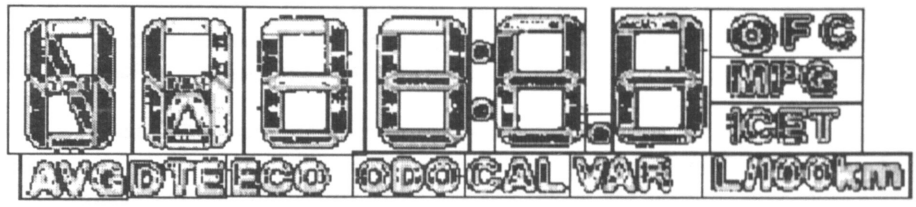

Figure 1: A VF display of compass/temperature/trip board.

Figure 2. The single segment fields of the board.

OBJECTIVES

The objective of this project is to develop computer vision algorithms combined with machine learning techniques to inspect various VF display boards.

APPROACH

Automatic visual inspection is one of the primary applications of computer vision. Visual inspection has broad applications in industry automation and covers the full range of technical difficulty in computer vision [BKD95, DaJ88, SNW95].

Because of its diverse application environment, it has been recognized that there is no pervasive generic solution in machine vision; each application requires a careful study of alternatives and perhaps even the invention of a new technique. Our approach to solving the VF display board is illustrated in Figure 3, which presents the overall view of the machine vision system designed for VF board on-line inspection.

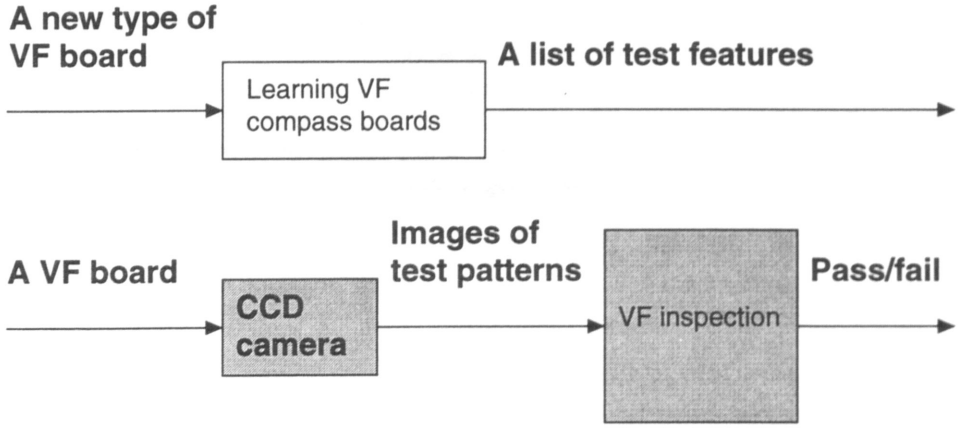

Figure 3. Overview of a machine inspection system.

The system consists of two major procedures, learning and inspection. The learning procedure is applied to every new type of VF board and produces a symbolic list of specifications for the inspection procedure. The learning procedure can be executed off the

production line. For every V board on the production line, the inspection procedure will generate a pass or fail signal based on image analysis of various test patterns. At the same time, the inspection procedure also saves the image that contains the defect evidence for further verification. The learning and inspection procedures in more detail are as follows:

For a new type of VF board, the learning procedure learns the board features from a good compass board of the type, and generates a symbolic representation of the compass board, which is referred to as the *Inspection Reference List (IRL).* The learning procedure employs a number of image processing techniques including binarization, tilt detection and correction, and computation of connected components.

The inspection procedure runs on the production line. The VF boards on the production line come in batches of the same type. Before a different batch of VF boards comes on the production line, the inspection procedure will read in the corresponding *test reference list* file, which contains the *master template* and the multiple test pattern lists for this type of VF board generated by the learning procedure. The inspection procedure is guided by the test reference list.

RESULTS

We have implemented the system described above on a PC computer under the Windows 3.1 operating system. The learning system has been deployed at Jabil Circuit, Inc., and the test program has been integrated into the Jabil test system.

CONCLUSIONS

We have presented a machine vision system for reliable inspection of various types of defects of VF boards. The system has two procedures, the learning and the inspection procedures. The machine vision system is robust in a plant environment, where lighting conditions can vary and shadow can occur in images, and the testing boards can be tilted and placed in various positions. During the learning process, which is performed off-line, the system attempts to learn the characteristics of each test pattern for every new type of VF board. The output of the learning procedure is a symbolic description of the test features of the particular type of VF board. The inspection procedure is performed on the production line. Therefore, the inspection procedure is designed to be extremely efficient in computational time.

IMPACT

The project has a significant impact on industry, since it automates the inspection of the VF boards in manufacturing lines and speeds up the test procedure, which ultimately leads to higher product yield. The project involves a number of students. During the project period, students visited the assembly plant at Jabil Circuit, Inc., and learned to solve practical problems. The results of this project can be used in a number of existing courses, including machine vision, image processing, and intelligent systems.

REPORT BRIEF

Fuzzy-Logic-Based Wheelchair System

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

AUTHORS:

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Department of Electrical and Computer Engineering

M. Jarrah
Jordan University of Science and Technology

BACKGROUND

Physically handicapped persons who are immobilized due to a serious spine injury are fortunate if they are able to control or even maneuver a specialized wheelchair. A person who is paralyzed from the waist down and has decent use of his or her arms has advantages over one who has no use of any appendage below the neck. A wheelchair system designed for either of these cases is a good candidate for fuzzy logic experimentation and implementation. The complexity of such a wheelchair system and the environment in which the wheelchair travels is high. Starting must be comfortable to the user, and stopping and turning must sometimes be precise or quick.

A typical electric wheelchair has two precision Swiss field DC motors whose actual speeds are controlled by desired-speed signals entered into a proportional, integral and derivative (PID) system by various mechanisms. These mechanisms can be a joystick or a system with a tube close to the user's mouth through which air is blown or sucked. This sip-and-puff mechanism causes the wheelchair to move in certain directions in response to pressure changes. Also, electric wheelchairs have user-friendly sensitivity adjustments, a variable top speed adjustment, two stages of dynamic braking for smooth controlled stops, an approximately 20-mile range, and a HI/LW speed toggle switch for quick changes.

Current PID systems allow good response time with minimum overshoot given a desire input signal from the user. These systems also meet, for example, the following specifications:

- 0 to 5.1 mph proportional control
- Climbing speed of 3.9 mph up to 9° ramp
- Rated at holding 250 lbs on a 14° hill

Several wheelchair systems are reported in the literature [1–5]. Tests on the powered chair supplied by the British National Health Service yielded the performance information shown in Table I.

Speeds	
Forward speed at maximum speed setting	0.6 m/s
Forward speed at minimum speed setting	0.2 m/s
Backward speed at maximum speed setting	0.4 m/s
Backward speed at minimum speed setting	0.05 m/s
Acceleration at maximum speed setting	0.5 m/s^2
Weight	120 kg
Typical battery life (intermittent use)	8 hours
Battery charging time	16 hours

Table 1. Performance of N. H. S.-type powered wheelchair

The table shows that a standard wheelchair has a long time constant, i.e., the response speed is slow. It takes too much time to reach full speed and turning is slow, causing a zig-zag motion due to overcompensation during turning. This results in a safety issue when operating the wheelchair in today's environment. One should consider a collision avoidance system to prevent impact with walls, furniture, etc. Such a system should be able to measure the range of objects in each of four directions. One way to do this is by using the user's vision to estimate the distances and feeding this information to the wheelchair control system in an appropriate way to ensure fast response and normal operation.

Speed, direction, and collision avoidance can be suggested by the user to the system. Such requirements increase the mathematical complexity of a PID control system and the length of control logic to fail-safe the system given other inputs. These complexities, the need to incorporate safety measures, and other regulations forward fuzzy logic control design. Fuzzy logic is compatible with user inputs such as too far, very close, or too fast.

OBJECTIVE

The present work will address the use of a fuzzy logic controller to control the wheelchair based on user fuzzy inputs. The design should incorporate the safety regulations as well as the speed commands, turn commands, collision avoidance, etc. A new design is proposed that will increase the maneuverability of the wheelchair, enhance safety, and increase the ability to reach out for 360 degrees. This is provided by using an extra actuator to facilitate rotation about the vertical axis.

APPROACH

The wheelchair mathematical model is considered next. This model is used to develop the simulation of the present control procedures. The model consists of the equations of the motions of the wheelchair, the actuator dynamic model, and the sensor dynamics. The simplified representation of the system is shown in Figure 1. The wheelchair system instrumentation includes speed measurement, direction, object detection, and road condition. These instruments are integrated in a sensor package used for controlling the wheelchair.

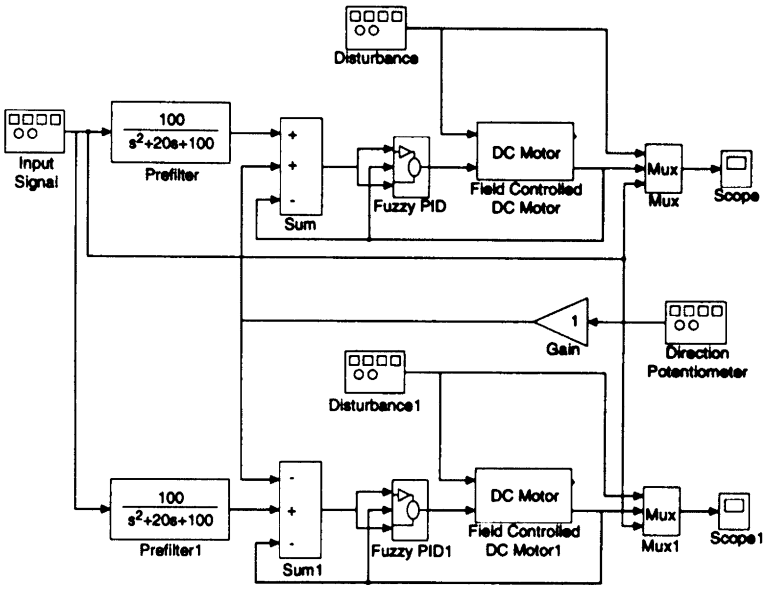
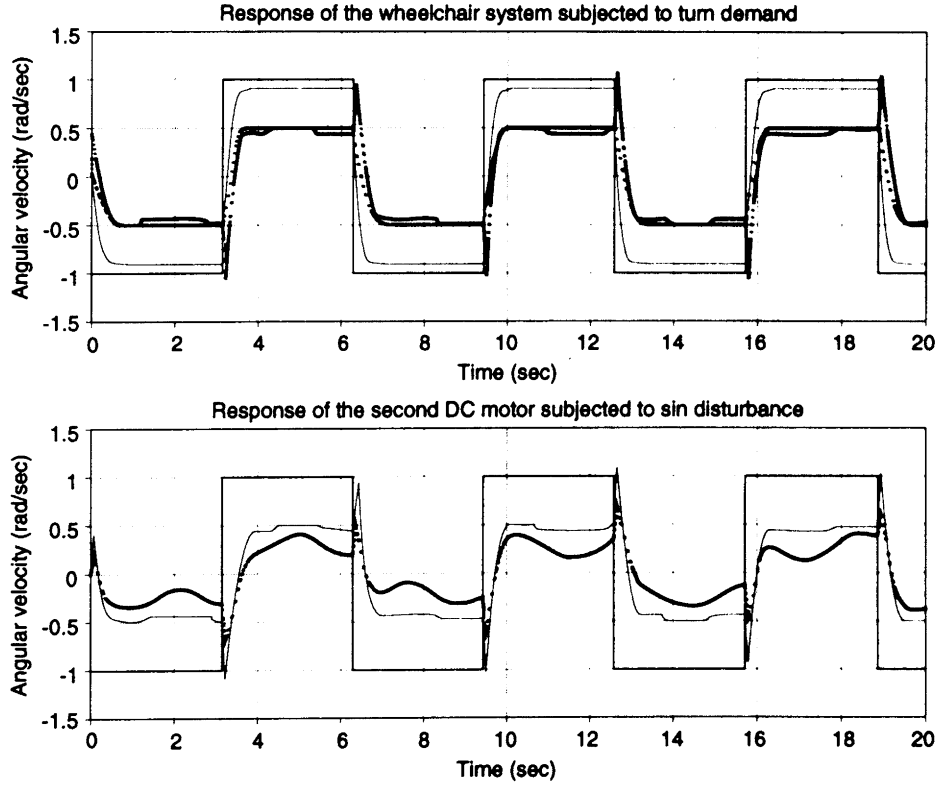


Figure 1: Simulation model for two DC- electric motors wheelchair system

RESULTS

The preliminary simulation results show that the fuzzy-logic-based controller can perform better than the classical controllers (Figure 2). The present system is flexible and robust to changes in the various inputs. The response is the regular PID controller for a given overshoot.



Thick lines are for regular PID controller. Others are for fuzzy logic controller.

Figure 2: Comparison between classical PID controller performance and the proposed Fuzzy-PID controller

IMPACT

This application outlines work that can open a new and needed area of research in the application of fuzzy set theory in designing wheelchair systems. The outcome of this research has excellent potential to be used by various manufacturing organizations, where it is expected to have a substantial impact on improving wheelchair control systems.

REFERENCES

[1] Keating, D. and Warwick, K., "Robotic Trainer for Powered Wheelchair Users," *1993 IEEE Systems, Man and Cybernetics Conference Proceedings.*

[2] Mazo, M., Rodriguez, F. J., Lazaro, J. L., Urena, J., Garcia, J. C., Santiso, E., and Revenga, P. A., "Electronic Control of a Wheelchair Guided by Voice Commands," *Control Engineering Practice*, Vol. 3, No. 5, pp. 665–674, 1995.

[3] Foque, R., and Lammineur, M., "Designing for Patients: A Strategy for Introducing Scale in Hospital Design," *Design Studies*, Vol. 16 No. 1, pp. 29–49, 1995.

[4] Mori, H., Kotani, S., and Kiyohiro, N., "Robotic Travel Aid HITOMI," *Proceedings of the IEEE/RSJ/GI International Conference on Intelligent Robots and Systems*, Part 3, 1994.

[5] Pruski, A., and Bourhis, G., "The VAHM Project: A Cooperation Between an Autonomous Mobile Platform and a Disabled Person," *Proceedings of the 1992 IEEE International Conference on Robotics and Automation*, 1992.

REPORT BRIEF

Automatic Braking System Using Fuzzy Logic

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

In the past twenty years, we have seen a profound enhancement in automotive performance. This is linked, on one hand, to the awareness of the automobile's contribution to the catastrophic rise in environmental pollution and, on the other hand, to the continued search for drive comfort and safety in order to transform the automobile from a simple tool to an integral part of daily life. Therefore, many vehicle functions are today performed through strategies implemented by various types of electronic control units. However, conventional control methods used in these units are often unsuccessful due to a lack of robustness, the necessity of a complex process, and elaborate "timing" procedures due to the continuous variation of parameters.

Several systems have been developed by automobile industries to improve the safety of the vehicle. Anti-collision control and cruise control systems by Eaton Vorad Technologies [2] are examples of modern control systems that improve vehicle safety. These are systems that warn a driver when a vehicle gets too close to an object. The systems warn the driver of the following:

- If the vehicle ahead is less than a minimum of five seconds away
- If they are overtaking a vehicle too rapidly
- If the vehicle ahead is slowing down or stopping suddenly
- If there is a vehicle in the blind spot in the right lane

Cruise control systems [3] use an infrared radar as a target sensor to calculate the distance between the car and the object in front. They also use an anti-lock braking system to decelerate the vehicle and a throttle controller to accelerate the vehicle. This allows the user to enter a desired speed, and the cruise control then adjusts the speed as obstacles occur. The system uses the distance between the car and the object in front, desired speed, and change in speed as inputs into a microprocessor. The brake pressure or throttle pressure is then calculated and the speed of the car is adjusted.

Vehicle-road interaction is difficult to model for arbitrary road conditions. In addition to the braking force, the parameters that affect deceleration of the vehicle are the rolling resistance of tires, aerodynamic drag, transmission resistance, and grade resistance. These factors contributing to deceleration in any braking system should be accounted for in the design of any automatic braking system. Such factors are affecting the vehicle acceleration in a non-linear fashion, which makes the controller design in the classical domain a formidable task.

The techniques of fuzzy control, based on expert knowledge and possessing intrinsic qualities of robustness and ease of implementation, seem to be an interesting alternative [1].

OBJECTIVE

The objective of this research is to develop and simulate an automatic braking system using fuzzy logic. The proposed system will be developed using ideas from two classical state-of-the-art systems, an anti-collision system [2] and an intelligent cruise control system as described [3].

APPROACH

A fuzzy controller will be developed for an automatic braking system for a car. The proposed system operates as follows:

- A sensor (radar) detects an object in front of a car.
- From the signal generated by the radar, the distance between the car and theobject can be calculated.
- When the car is at a certain distance from the object, the car will automatically start to decelerate by applying brake pressure.
- If the object in front of the car is moving, then the controller will regulate the car speed in order to maintain a safe separation distance.
- If the object is not moving, then the car will come to a stop before it hits the object.
- Manual braking system override will be applied after braking in order to maneuver the car past the object.

The fuzzy controller uses the distance between the car and the object, as well as the closing car's speed, as inputs and then calculates the brake pressure needed to safely control the car.

The braking force developed on the tire-road interface [4] is given by:

$$F_b = \frac{T_{b-\sum I\alpha_{an}}}{r}$$

where T_b is the applied brake torque, I is the tire moment of inertia, α_{an} is the angular deceleration, and r is rolling radius of the tire.

The resultant retarding force can be expressed as follows:

$$F_{res} = F_b + f_r W \cos(\theta_s) + R_a \pm W \sin(\theta_s) + R_t$$

where f_r is the rolling resistance coefficient, W is the vehicle weight, θ_s is the angle of the slope of the road with respect to the horizontal axis, R_a is the aerodynamic drag, and R_t is the transmission resistance.

The acceleration of the vehicle during braking is given by:

$$a = -\frac{g}{W} F_{res}$$

where g is the gravitational acceleration.

The automatic braking system should estimate the $\left(\frac{a}{g}\right)$ parameter and limit the tire deceleration during braking to prevent a tire lock-up. This will be affected by the operating conditions, which have a wide range of variation. Road condition is simulated by the

coefficient of friction (μ). An optimal brake pressure at one road and load condition is not acceptable at different operating conditions. Therefore, present anti-lock brake systems require the actual measurements of the tire status during the braking.

The present fuzzy controller has two inputs—the distance between the car and the object and the closing speed of the car. It has one output—the brake pressure. The estimate of the road condition is produced by the rate of deceleration for a given brake pressure. This will require the addition of an accelerometer to the instrumentation. This measured acceleration will be used to tune the gain of the brake pressure to keep $\left(\frac{a}{g}\right)$ below that corresponding to tire lock-up. If the maximum deceleration developed by the braking system will not bring the car to a safe stop due to road conditions, due to failure in the braking system, or due to front vehicle maneuvers, then a warning signal should be issued for the driver to take corrective action by maneuvering the vehicle out of the situation. An overall system diagram is shown in Figure 1.

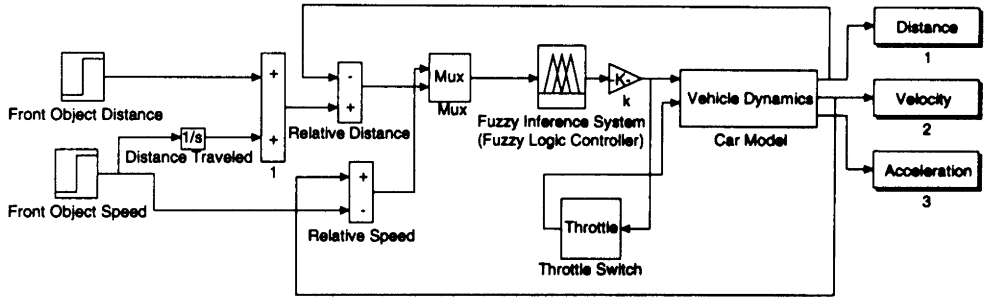

Figure 1: Fuzzy controller model for the proposed automatic braking system

RESULTS

Extensive simulation was carried out using a general mathematical model for the vehicle dynamics. Two simulations are presented: the first simulates a car going into a wall at 40 m/sec and starting off at 100m away from wall. The second simulation was for a car following a vehicle moving at 10 m/sec and coming to a sudden stop after 5 seconds into the simulation.

- Initial speed of car = 40m/sec
- Initial distance between car and object in front = 100m
- Object in front is stationary or moving at 10 m/sec speed and coming to a sudden stop after 5 sec

The first simulation is a worst-case condition. It simulates a car going 40m/sec straight into a wall. It can be seen from Figure 2 that the controller starts to apply brake pressure resulting in deceleration reaching a maximum at -12.5m/sec^2. This causes the car to come to an abrupt stop within 20m of the wall. This simulation indicates that the controller can be used in the most severe of conditions.

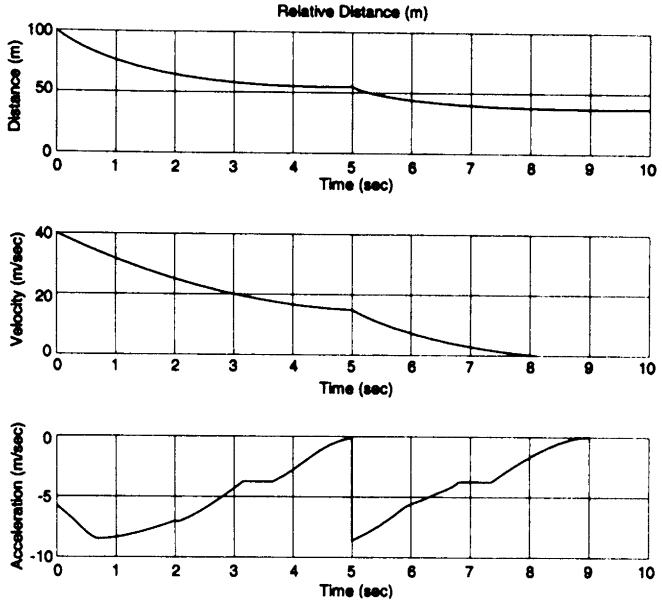

Figure 2: Distance output, speed output, and acceleration output

CONCLUSIONS

The results of the simulations show that a fuzzy controller for an automatic braking system can be implemented. Even for the worst-case situation of a car heading into a wall at 40m/sec, the system can bring the car to a safe stop without hitting the wall. Response time and brake pressure are the essence of this system. The quicker the response time and the smoother the brake response, the quicker the car will come to a stop without having its wheels lock up. The exception is the last simulation where the deceleration is -12.5m/sec^2, with the consequent loss of directional stability and control. Also, the effect of the brake pressure on the speed of the car could be calibrated more accurately by refinement of the rule base.

IMPACT

This application has potential for improving existing automatic braking systems. Using fuzzy logic opens a new way for enhancing many existing systems. This work will show how easy and flexible fuzzy modeling is in automotive applications.

REFERENCES

[1] Boverie, S., Demaya, B., Le Quelle, J. M., and Titli, A. "Contribution of Fuzzy Logic Control to the Improvement of Modern Car Performance," *Control Engineering*, Vol. 1, No. 2, 291–297, 1993.

[2] Marjorie Sorge, "You're Too Close Warns System," *Words World*, Vol. 29, 58–59, April 1993.

[3] Ulf Palmquist, "Intelligent Cruise Control and Roadside Information," *IEEE Micro*, Vol. 13, 20–28, February 1993.

[4] Wong, J. Y., *Theory of Ground Vehicles*, John Wiley & Sons, Inc., 1993.

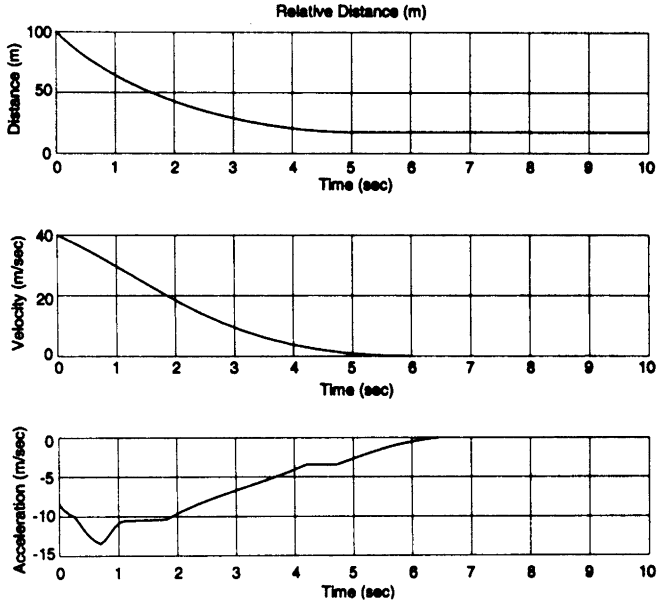

Figure 3: Distance output, speed output, and acceleration output

REPORT BRIEF
Automated Check Reading: Myth or Reality?

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

Until now, banks have been reluctant to invest in document reading automation for two specific reasons. First, predictions of a paperless world have influenced banks in their long-term capital investment. Second, the commercially available technology is too expensive and too inadequate (in terms of labor savings) to justify a business case. As discussed in this paper, these reasons are no longer valid. The volume of checks in the US has increased steadily by two to three percent yearly for the past five years. Advances in computer technology and pattern recognition, coupled with continued customer preference for payment by check, make imaging-based systems a viable solution not only to save labor but also to create new services.

OBJECTIVES

The objective of this project is the development of an integrated check reader (ICR) that automatically reads all relevant information fields in a check and uses corroboration and validation to obtain extremely low error rates (less than one in 10,000).

RATIONALE

According to the Federal Reserve, banks spent 10 billion dollars to clear the 67 billion checks received in 1995. Large banks such as the San Francisco Bank America process more than 15 million checks every night. Because the volume is increasing at about 2 billion checks per year, banks continue to invest to further reduce delays in the clearing process. In 1994, banks spent $16.3 billion on image-based technology. This total will grow to an estimated $19.8 billion by 1997.

CHALLENGES

In remittance processing, typically five target fields need to be identified and recognized: signature presence, payee name, legal and courtesy amounts, and date. The challenge in recognizing each of these fields will be described, but first a brief discussion on image quality is important since it is a critical factor affecting the ICR read rates.

Image Quality

Because of the wide variation in document quality, the problem of adjusting a scanner for the highest recognition rate will always be an issue (Figure 1). Ideally a gray-level image can be captured, allowing software-based background removal to clearly highlight the text

to be recognized. Unfortunately, the cost associated with using gray-level image processing is still much higher than the cost associated with using the traditional binary output. Furthermore, in some cases banks have already invested in a binary image system. The standard spatial resolution for check image processing is 200 dots per inch. This occasionally causes the characters to be broken (Figure 2). This could be increased (e.g. to 300 dpi, as is common in forms-scanning applications), since machine print recognizers are more accurate at higher resolution. However it is doubtful that the standard will shift to 300 dpi soon. Figure 3 shows a skewed image creating difficulties in field extraction.

Figure 1. Image quality problem

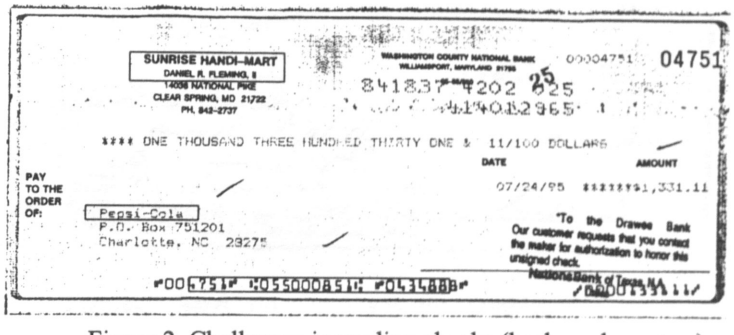

Figure 2. Challenges in reading checks (broken characters)

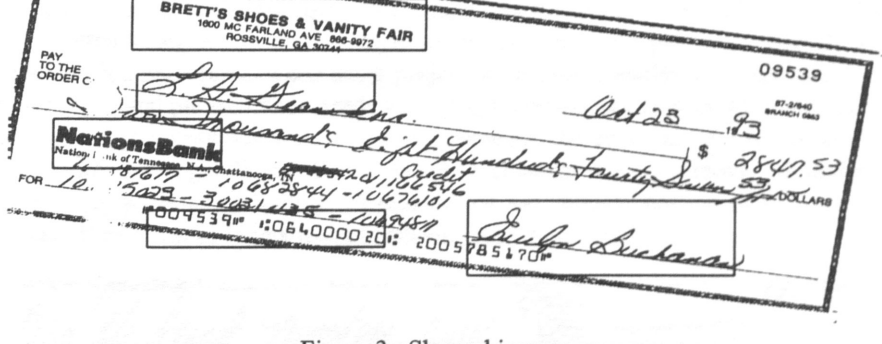

Figure 3. Skewed image

Field-specific recognition challenges

The challenge of locating and recognizing the five semantic types typically found in remittance applications is now described. These include the legal amount field, the courtesy amount field, the date field, the payee name field and the signature field.

Legal amount recognition challenge

About 80 percent of machine printed business check images tested had a legal line. On most personal checks and some business checks, the legal amount is handwritten, posing a

major challenge (Figure 5). Machine-printed keywords can often be used to locate the legal line, which can then be treated as a phrase.

Most of the problems discussed thus far can be handled well by an ICR system. However, some characteristics unique to checks pose special difficulties. For security reasons, the printing of the legal amount might use "protection fonts" or a highly graphical representation (Figure 4).

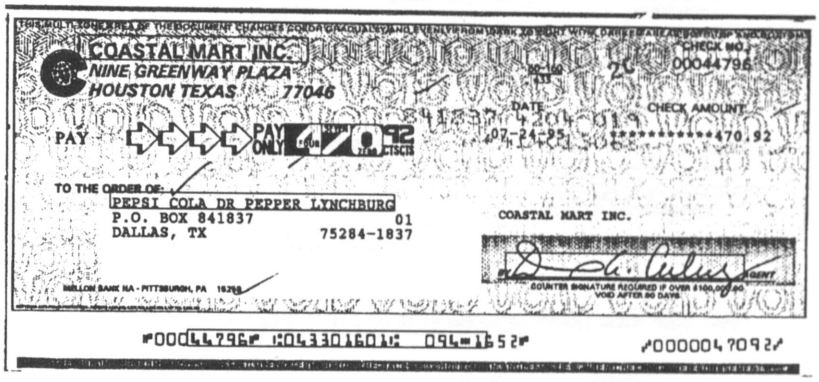

Figure 4. Challenges in reading checks: unusual font.

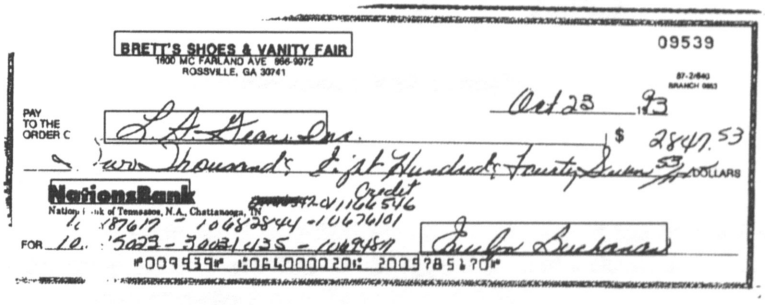

Figure 5. Handwritten legal amount example

Legal phrase matching is an extremely challenging task for several reasons. First most legal lines are written using a full cursive style as opposed to hand printed. Second, word separation is often ambiguous when using projection or profile analysis. Before attempting recognition, the legal phrase image needs some special processing (Figure 6). In addition to overhangs from the previous line, one must consider the removal of various artifacts associated with this legal field. Some issues to consider are 1) removal of underline without deleting portions of writing, 2) removal of the numeric portion of the monetary amount, and 3) removal of long strokes to fill any gaps in the field.

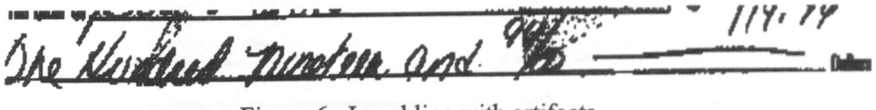

Figure 6. Legal line with artifacts

Once the image has been prepared, legal line phrase matching can be accomplished in two modes. First, in a parallel mode, the legal field is recognized using a fixed-size word lexicon consisting of numeric words "one" through "twenty", "thirty" through "hundred" in steps of 10, and "thousand". This assumes that clear word boundaries can be found, which is not always the case. Alternatively, in a serial mode, the courtesy amount is recognized first and the result used to generate a lexicon for the legal line field.

Courtesy amount recognition challenge

The *courtesy amount* is the numerical character representation of the amount on the check. While the legal amount may not be present on all checks, the courtesy amount should (in theory) always be present.

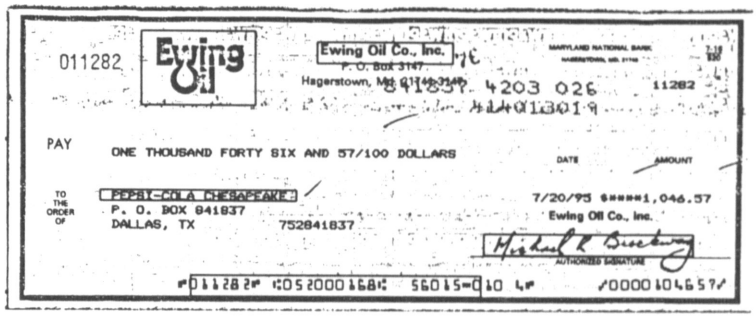

Figure 7. Example of courtesy amount fused with date field

Courtesy amount slash example

Date recognition challenge

The *date* field is the most difficult target to isolate for several reasons: it has only a few characters; it can be located practically anywhere in the upper region of a check; and it may be fused (in almost any spatial orientation) with the courtesy amount.

Payee name recognition challenge

The *payee name* field is the easiest field to locate and to recognize, as it usually exhibits a clean background and good quality characters. Figure 8 illustrates an example in which the payee name is above the legal amount line. A purely geometric-based location algorithm would have misidentified the two strings. Such cases motivate our use of semantic clues to correctly parse the target fields.

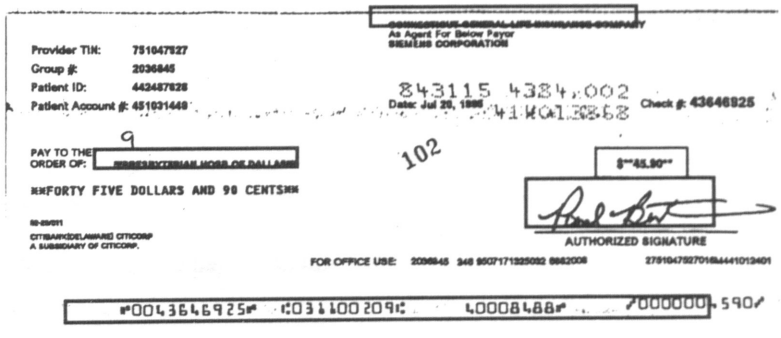

Figure 8. Payee name example

Signature detection challenge

Signature detection is not as trivial as simply counting pixels in a given area. Stamped directives (see Figure 2) should also be reliably detected. Figure 9 illustrates an example of where signature detection will (and probably should) fail.

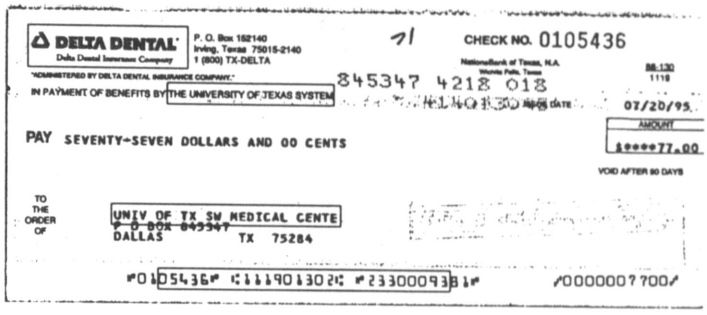

Figure 9. Signature detection challenge

RESULTS

Extensive field testing with 100,000 checks, consisting of both machine-printed and hand-written checks, is currently in progress. Preliminary results indicate a reasonable success rate with courtesy amount recognition (CAR). Recognition of handwritten legal amount (LAR) on the other hand, has presented some major challenges, mainly due to the very poor writing often found on these checks.

CONCLUSIONS

Despite the advent of new electronic payment techniques, check-writing remains the primary method Americans use to transact payments. Meanwhile, advances in computer technology and pattern recognition now allow the design of highly accurate ICR image-based systems at an affordable cost. The cost of check processing is directly asso-ciated with labor cost, so that gains in recognition capability can create immediate savings for the financial institutions or clearinghouses.

In conclusion, automated check-reading is still in a developmental stage. To that extent, commercialization is still a promise yet to be delivered. The authors deliberately refrain from taking a stand on whether automation will ever come about. In fact, one can argue that with the advent of electronic banking, checks may have the same fate as the dinosaur.

IMPACT

This project has had a very beneficial impact on education and industry. Active collaboration between the industrial partner, Mr. Gilles Houle of TRW, and the project investigator, Prof. M. Shridhar, has resulted in the development of new approaches for machine recognition of bank checks. A more exhaustive report of this work was presented at the International Association for Pattern Recognition Workshop on Document Analysis Systems (October 14-16, 1996). The paper was judged as the Best Paper in terms of the quality of the work, the presentation, and the completeness of the project.

Two masters theses have resulted from this project. Since the start of this project, four senior design projects have been completed. During the summers of 1996 and 1997, several undergraduate students participated in this project under the NSF-REU grant. Two journal articles and four conference papers on this topic have also been published.

ACKNOWL-EDGMENT

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REPORT BRIEF

3-D Imaging and Its Applications in Manufacturing Processes

June 18, 1997

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BACKGROUND

In industrial applications, for image processing and vision technology to be integrated into operational processes, it is important to adapt the technology in a task-specific environment with modest efforts and with a relatively short development time. It is of great interest to industry that the imaging technology be only a small portion of the automation process, both in cost and in time. Therefore, an easy-to-use tool for designing an imaging and vision application becomes critical to achieve this objective. The research project was focused on building an easy-to-use and robust image processing and feature extraction library and its software environment. The library consists of image processing functions (filters) and vision algorithms. The environment is a graphic-user-interface (GUI) tool chosen for ease of use and for developing new user-defined algorithms.

Working with Perceptron, a joint project sponsored by the Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST) was developed in order to investigate and advance technologies that are critical to manufacturing applications of laser-based, three-dimensional imaging systems.

OBJECTIVES

The objective of this study was to produce a library of 3-D range imaging algorithms that can effectively employ imaging and vision techniques and can be applied to an industrial automation environment. A feature extraction tool was built specifically for 3-D range image applications in manufacturing processes. The library of the algorithms developed in this study was formatted into an easy-to-use imaging tool that consists of many useful algorithms and functions.

APPROACH

The major tasks for the UM–Dearborn team were to design and implement the feature extraction library. The collaborators at Perceptron and ERIM were to design and build a test bed for the technologies developed at UM–Dearborn. The applications were focused on the automobile manufacturing processes for increased productivity and quality assurance.

RESULTS

The research activities at UM–Dearborn generated a large group of functions that were classified into three function/filtering and algorithm libraries. Three libraries were implemented: (1) a filter library, (2) a morphology library, and (3) a feature extraction library. The research also generated a software package that hosts the functional libraries and has an image manipulation tool. The software environment enables the researchers to study algorithm development interactively with other functions.

CONCLUSIONS

This joint project has been completed and the software package and function libraries were delivered to our industrial partner, Perceptron, and the research partner ERIM. The ATP examined the technical results and the relevant economic benefits that have been generated from this joint project.

IMPACT

This project provided a funding resource for us to establish a 3-D imaging laboratory. A number of graduate and undergraduate students worked on this project and its related tasks. Three graduate students were sponsored through research assistantships during their graduate programs. A number of undergraduate students were hosted at UM–Dearborn and learned and designed 3-D imaging and vision functions for industrial applications. The materials resulting from this research project have been used and will continue to be used in our machine-vision-related graduate and undergraduate courses such as ECE 586 (Image Processing), ECE 589 (Multidimensional Signal Processing), and ECE 581 (Signal Processing Architecture).

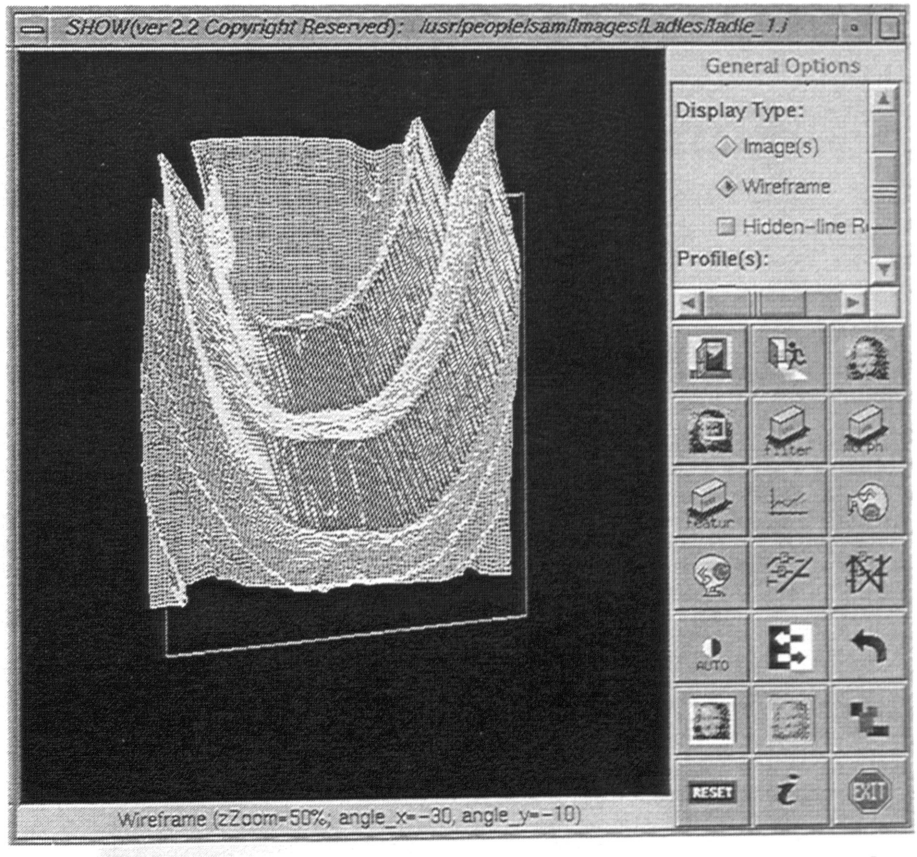

Figure 1: The software environment developed in this project enables us to study an object that has been imaged with a 3-D laser sensor camera.

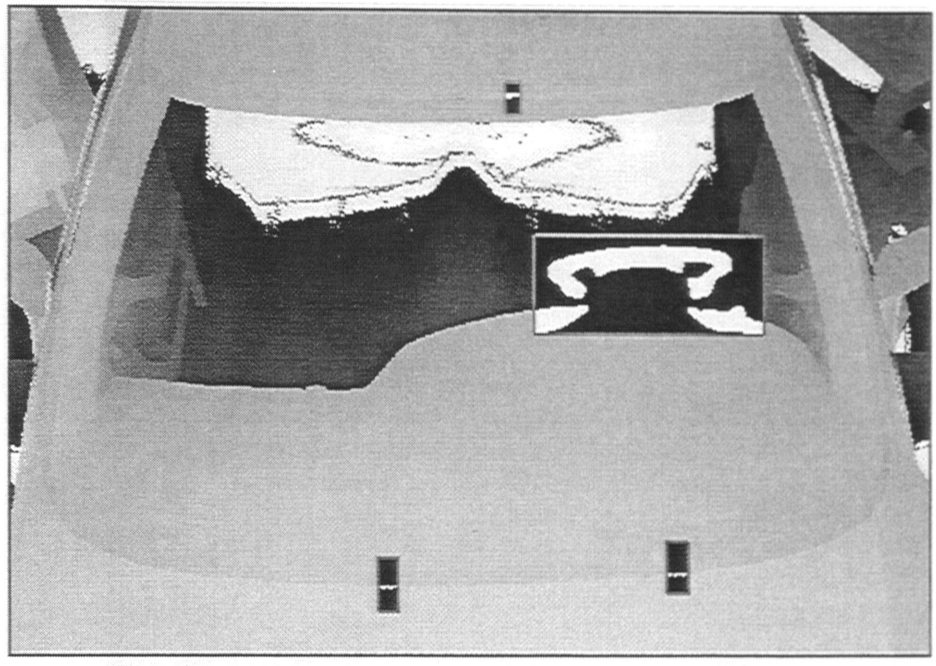

Figure 2: The windshield installation application. The range data are interpreted by the algorithm library, and a group of features of interest have been identified for robot guidance in this demonstrative example.

Department of Industrial and Manufacturing Systems Engineering

REPORT BRIEF

An Intelligent Tolerance Design Advisor for Injection Molding

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
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Research Assistants

BACKGROUND

Tolerance design is a critical step in the injection molding process and an important link between design and manufacturing. For an injection molded part, loose tolerances make the manufacturing process much easier, but they cannot ensure the part's functionality; tight tolerances ensure the part's functionality, but they create more manufacturing difficulties and increase costs. Tradeoff decisions can be made by designing and verifying the tolerance assignments based on both design requirements and manufacturing capabilities. In Ford Motor Company, emphasis has been put on the development of a design advisor for injection molded parts under the DFM (design-for-manufacturing) environment. The tolerance design portion, however, is one of the bottlenecks of their system. This project, which is funded by CEEP, REEDF, and Ford, enhances the design advisor by providing a tolerance design module.

OBJECTIVES

The objectives of this project are threefold:

1. To develop methodologies and a computer model that can not only perform the primary tolerance design tasks for injection molded parts, but also evaluate the part's manufacturability from the viewpoint of rationality of tolerance
2. To acquire, represent, and integrate tolerance-related knowledge from both design and manufacturing areas to support intelligent tolerance design under the DFM environment
3. To develop strategies and algorithms of tolerance optimization by considering both tolerance manufacturability and its loss functions

APPROACH

Technical approaches used in our project are:

1. Modularized method for developing main function models as well as the linkages among them
2. Feature-based design method for injection molded parts using the I-DEAS modeling tool
3. Multiclassification of design and manufacturing-related factors, as well as hierarchical knowledge structure to support decision-making of tolerance design and verification

4. Fuzzy logic method to represent empiric knowledge provided by injection molding experts
5. Statistical analysis methods including Taguchi loss function to realize tolerance optimization

RESULTS

1. The overall system structure was designed as shown in Figure 1. In addition, a software environment has been built to support this structure. Its components and usage are: (a) Solaris C & C++ for development of the reasoning machine in the tolerance design model, (b) I-DEAS Master-Modular 3.0 for part modeling, and (c) Element-Environment 2.0 for interface design and DFM knowledge establishment.

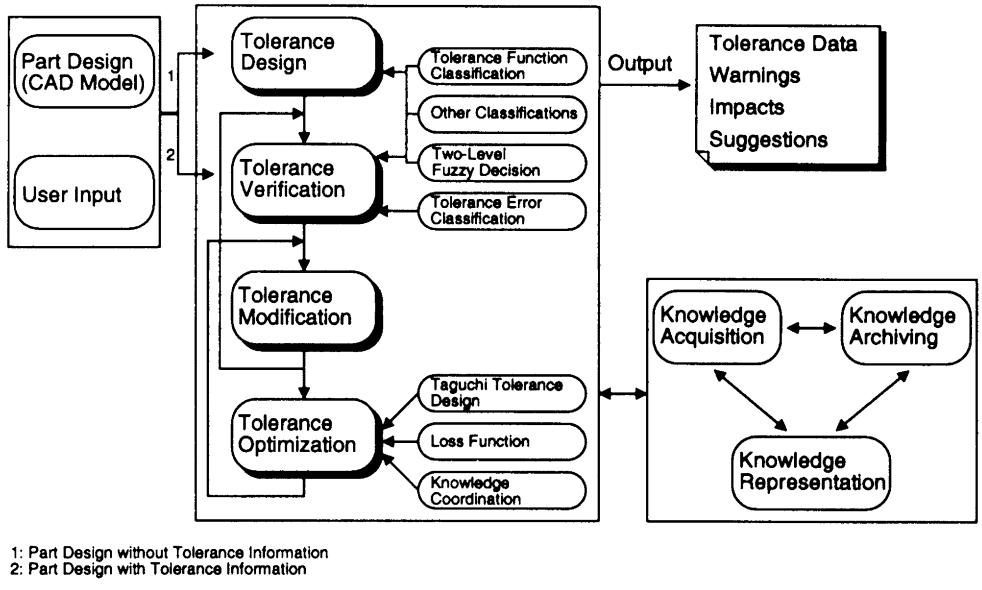

Figure 1. The System Structure of Intelligent Tolerance Design Advisor

2. I-DEAS features catalogs have been created that contain the most-often-used geometric form-features in injection molding. All these features have been defined as parametric models. Additionally, a feature data structure that can represent tolerance values and their associated manufacturability information has been designed.
3. A multiclassification of factors that influence tolerance in injection molding has been established. Based on the classified catalogs, i.e., tolerance function, material, part design, mold design, and machine capability, the corresponding hierarchies of knowledge base structure were developed.
4. A software prototype was developed. It has two main functions: (a) when a part design does not include any tolerance information, the model can generate the tolerance specifications based on the primitive part design as well as manufacturing capability information; (b) when a part design already contains tolerance information, the model can also be invoked for verifying the manufacturability. Not only the tolerance values but also the manufacturability feedback information such as machine capabilities, manufacturing costs, and suggestions can be generated.

CONCLUSIONS

1. Tolerance design for injection molded parts is different from that for metal cutting parts. It is affected by a number of factors. A feasible design can be obtained by not only referring to some design standards, but also, more importantly, taking experts' experiences into account on the basis of the real industrial environment.

2. Part modeling is still a key issue for tolerance design. A feature-based model can represent not only the part's GD&T information, but also its manufacturing requirement information. It has more advantages if used under a DFM circumstance.
3. A multiclassification of tolerance design factors significantly helps the knowledge base establishment and knowledge reasoning. Based on this, we can deal with the tolerance design in different stages by considering different levels of classification.
4. Only by integrating all the necessary information from both design and manufacturing areas can a tolerance design be realized under a DFM environment. Also, manufacturability evaluation should be implemented at any stage while the part is being designed. The long cycle from design to redesign can be avoided, and significant cost savings will be achieved.

IMPACT

It is believed that the methodologies and technologies developed from this project can be easily adapted to other industrial applications. For example, the tolerance design for a die-casting project in Ford involves similar issues. The developed system structure, part feature catalogs, and established multilevel classification scheme in this project can be expanded to other design and production processes for implementing concurrent engineering philosophy.

The concepts and technologies involved in this project can also be integrated into our engineering curriculum, such as in undergraduate design courses or as thesis topics of graduate programs. Currently, two MS students are working on this project. The software used in this project, including I-DEAS and Element-Environment 2.0, represents the latest CAD and knowledge-base technology and is currently used by companies such as Ford. This project will have an impact on education by providing faculty and students with the opportunity to learn and experience advanced tools for engineering design and knowledge processing.

ACKNOWLEDGMENT

We would like to thank Dr. Shuh-Yuan Liou, Mr. John Li, Mr. Lyn Depew, and Mr. Yong Pan, all of Ford Motor Company, for their assistance in providing valuable suggestions and materials and for letting us share their working environment, including the latest versions of software.

REPORT BRIEF

A Diagnostic Monitoring System for Manufacturing Processes

June 18, 1997

STATE OF MICHIGAN RESEARCH EXCELLENCE AND ECONOMIC DEVELOPMENT FUND

SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER: State of Michigan

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BACKGROUND

An efficient and effective diagnostic monitoring system is essential for advanced manufacturing processes to ensure the quality of manufactured parts; however, the self-diagnosis capabilities of machine tools continue to lag far behind the need. Instead of conventional failure or preventive maintenance, the trend today is to monitor the condition and behavior of production machines and to predict the need for maintenance with minimal interruption to the production process. This project enhances the predictive maintenance practice by developing a diagnostic monitoring system for manufacturing processes, with particular emphasis on the milling process.

OBJECTIVES

- Implementation of a computer-based diagnostic monitoring system for manufacturing processes using modern sensor and signal-processing techniques
- Application of evaluation algorithms to different kinds of indices obtained from output signals to improve the decision-making process

APPROACH

1. Design the architecture of a self-diagnosis module for CNC machines.
2. Develop a set of classification algorithms that are critical to the decision-making procedure. These algorithms include:
   a. Hard boundary information gain algorithms
   b. Soft boundary information gain algorithms
   c. Neural network algorithms: BP network, radial basis function network, composite radial basis function network
3. Detect chatter occurrence in the milling process by means of the cumulative moment (CM) index in time-frequency distribution.
4. Index evaluation and analysis for diagnostic monitoring of manufacturing processes.
   a. Index extraction in the following four categories:
      - Time Domain Indices:
        † Mean and Median
        † Variance and Standard Deviation
        † Skewness and Kurtosis

- † RMS and Crest Factor
- † Peak Value and Peak Location
- † Peak-to-Peak Value
- † Autocorrelation
- † Short-Time Crossing Rate
- † Short-Time Energy

- Time-Frequency Domain Indices:
  - † Cumulative Moment

- Frequency Domain Indices:
  - † Peak Value
  - † Peak Location
  - † Frequency Area
  - † Frequency Energy
  - † Power Ratio
  - † Overalls

- Autoregressive Model Indices:
  - † AR Coefficient Matrices
  - † Damping Ratio
  - † Nature Frequency
  - † RMS of Prediction Errors

b. Signal pre-process by statistical characterizations such as histogram, normal probability plot, and hypothesis.

c. Index evaluation according to classification algorithms, which include the information-gain-based multiple voting (hard boundary and soft boundary) and neural networks (BP, radial basis function network, composite radial basis function network).

RESULTS

- The architecture of the system has been designed and a software shell has been developed.
- Some advanced signal processing algorithms have been developed and tested on tapping and transmission data.
- The cumulative moment index is calculated based on the pseudo-Wigner-Ville distribution in time-frequency domain for detecting chatter occurrence in milling processes.
- Some indices dedicated to diagnosing manufacturing processes have been extracted, evaluated, and analyzed for better and faster decision making.
- Further improvement is still ongoing.

CONCLUSIONS

- A preliminary diagnostic system for machine tools has been partially developed.
- No single classification algorithm is considered to be the best to classify both tapping data and transmission data. There are tradeoffs in using these algorithms.
- The pseudo-Wigner-Ville distribution is suitable to analyze the chatter occurrence. The cumulative moment is a sensitive index with less computational burden in on-line detection for chatter vibration.
- The quality and process are improved through better and faster decision making by using the evaluation and analysis of different kinds of indices obtained from the manufacturing process.

IMPACT

The authors of this proposal have made many contacts with industry, such as GM, Ford, Chrysler, Perceptron, etc. The problems addressed in this project actually came directly from industry. In Michigan, especially in the Detroit area, the diagnostic monitoring of manufacturing processes was identified as one of the most critical challenges. The advances of diagnosis technology will have an enormous impact on local industries. Results of this project were also used in several courses, including ECE 569, IMSE 536, etc. One graduate student research assistant is working on this project.

ACKNOWLEDGMENT

Our grateful acknowledgment and appreciation is given to the Research Excellence and Economic Development Fund (REEDF) of the State of Michigan for its financial support, which enabled us to acquire necessary instrumentation, hardware, and software for this work. The authors also want to thank Dr. Xiao Li for his efforts on this project.

REFERENCES

Chen, Y. B., Li, X., and Orady, E., "Integrated Diagnosis Using Information-Gain-Weighted Radial Basis Function Neural Networks," *Computers in Industrial Engineering*, Vol. 30, No. 2, 1996, pp. 243–255.

Chen, Y. B., Li, X., and Orady, E., "Chatter Detection in Milling Processes via Time-Frequency Distribution," *Proceedings of the 5th Industrial Engineering Research Conference*, May 1996, pp. 59–64.

Chen, Y. B., Li, X., and Orady, E., "An Integrated Neural-Fuzzy Decision System for On-Line Monitoring of Machining Processes," *Proceedings of the 4th International Fuzzy Systems and Intelligent Control Conference*, April 1996.

Chen, Y. B., Li, X., and Orady, E., "Chatter Detection and Assessment in Milling Process via Time-Frequency Distribution," *International Conference on Manufacturing Engineering and Science*, June 1996, pp. 291–296.

REPORT BRIEF

A Knowledge-Based System for Product Design Features and Manufacturing Process Associativity Analysis

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

The emergence of global markets for engineered products and the resulting increase in competition in markets traditionally dominated by US manufacturers has led to calls for increased productivity. Attention is particularly focused on understanding engineering design and developing new methodologies to increase the efficiency of the design process. One such method is concurrent engineering (CE). CE has focused on developing the tools and techniques for designing products. However, design in many industries is evolutionary, consisting primarily of incremental changes to existing products. This is known as the variant design engineering approach. While concurrent engineering is concerned with integrating people with traditional engineering skills, the variant design engineering approach is concerned with empowering people with new skills by giving direct access to complete knowledge about design and manufacture of parts, with the philosophy of "*the knowledge is not generated at design time, but retrieved from an engineering database which completely documents existing designs.*"

OBJECTIVES

To consider this issue, a program entitled Direct Engineering® was launched at Ford Motor Company. DE® is an integrated and computer-based environment that provides the engineer with direct access to complete knowledge and historical data regarding the design and manufacture of a product or a similar product as it is being designed and developed. A new product can be developed as a variation of an existing model. This will provide both manufacturability and functionality analysis capability. Figure 1 illustrates the process of engineering in this environment.

This research has developed a decision-tree structure that will associate parametric and features design data with manufacturing features of an AC hose. The tree structure will provide a mechanism for the development of a rule-based system for manufacturability analysis and process assembly planning, concurrently.

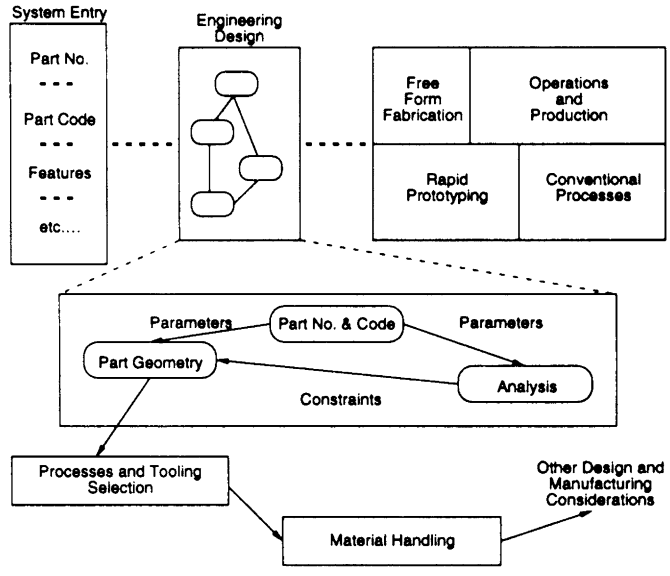

Figure 1

APPROACH

Features-Based Design: From a designer point of view, the feature can be defined as a specific design functionality. Features are defined by a set of parameterized data. The designer will define a set of geometric constraints and engineering relationships that are used for creating the geometry of the object and also for establishing the associativities among the objects within the design itself. From a manufacturing point of view, a feature can illustrate a certain manufacturing process. In a feature-based design environment, features could be used to illustrate the associativity between both design and manufacturing.

Group Technology: All manufacturing tasks require creating, storing, transmitting, analyzing, and modifying data. There is a need to standardize, automate, and integrate these data-manipulating functions in order to achieve total automation and integration. Typically, data may consist of: (1) *Product Data* describing the item to be designed and fabricated, (2) *Process Data* describing the manufacturing capabilities available and necessary to fabricate the part, and (3) *Rules Data* to control design and manufacturing associativities. Rules data may include procedures, specifications, analysis programs, and producibility criteria. The objective is to interrelate all of this data using computer architecture to arrive at the integration level, while maintaining interaction with the overall environment. The application of classification and grouping methodology in the optimization-of-process-planning task and the control of the manufacturing activities is considered to be a feasible and viable approach to the solution.

The Decision Tree and the Design Procedure: The part selected for this study is an automobile AC hose assembly. The AC hose assembly consists of two sections, tube and hose. The hose section does not have any major features. It consists only of a clip. The tube assembly consists of a series of standard design features that includes crimp, manifold, female and male spring lock connectors, clip, bracket, orifice, T-joint base and branch, male o-ring nut, etc. Associated with these features there is a series of operations required to perform setup and the assembly associated with each feature. Figure 2 illustrates the operational sequence for setting the assembly of the suction side of an AC hose on an engine.

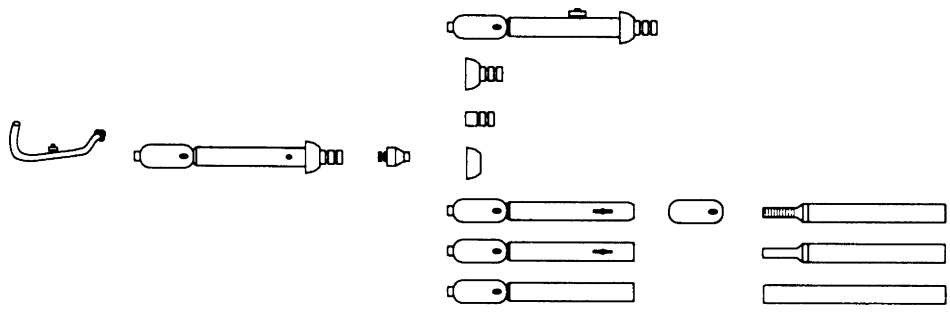

Figure 2

The operations associated with each assembly segment are identified. For example, to assemble the ferrule connector to the tube, the operational sequence consists of the steps shown in Figure 3:

Step 1: Cut off to the dimension
Operation Code – 10

Step 2: Reduction
Operation Code – 30

Step 3: Grooved
Operation Code – 40

Step 4: Assembled to the connector

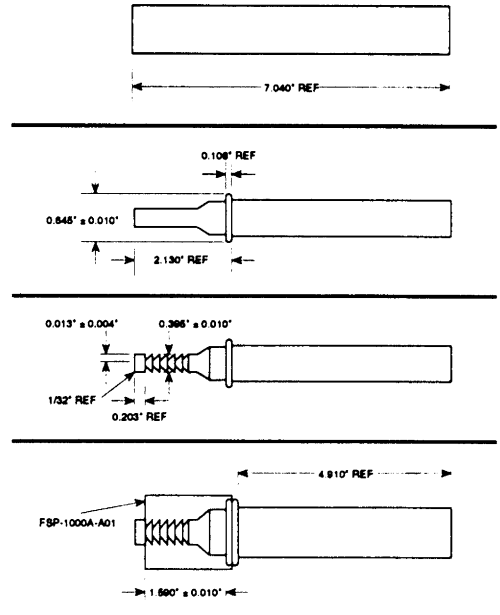

Figure 3

All operations are identified and coded using a decision-tree structure. This code is used to retrieve required specifications and operational setup. Finally a process and assembly decision tree is developed. The process template for process planning and KB system development uses information from plants all around the world, including the US, Mexico, and Europe. The design specifications and data are retrieved from the I-CAD modeler, which is used for the design of the AC hose.

RESULTS

⇒ **Increased** design efficiency by 50% and reuses the existing design and tooling for new programs : *Variant Design Process and Direct Engineering*

⇒ **Provided** optimization tools for product design and manufacturing engineers

⇒ **Established** a standard structure to retain engineering knowledge

CONCLUSIONS

This project allowed the PI to further investigate and justify the application of decision-tree and group-technology classification in the development of both design and process planning taxonomy for implementation of a KBE system for integrated design and manufacture.

IMPACT

- Student knowledge of the advanced techniques for computer-aided design and process planning
- Development of an anatomy for both the process/assembly flow and the structure for the data base
- $25K matching funding from Ford
- I-CAD software donation ($100K)
- RRM site
- Direct Engineering® book (in progress).

REPORT BRIEF

Quantifying Customer Perceptions of Vehicle Characteristics

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

To be acceptable, a passenger car or light truck is expected to have reasonably high quality at a competitive price. Acceptable quality and cost are now minimum requirements. Over the last decade a new criterion in automotive product design has emerged. Now the design in a diverse range of areas must elicit positive perceptions from customers. Examples include acceptable engine starting characteristics (e.g., "reassuring" starter motor sounds, a responsively quick start time); a horn's sound that reflects the desired image of the vehicle; headlight beam patterns that are pleasing to the driver; a passenger compartment that appears spacious and thoughtfully designed; instrument panel controls that convey consistency and attention to detail in their design; seats that are comfortable; and vehicle performance that is quick, quiet, and smooth. Perceptual requirements often are not systematically incorporated into design specifications. Reasons for this often include the lack of appropriate design tools, methods, and training to enable product design engineers to adequately address customer perceptual requirements. Methods are needed that quantify, in a meaningful way, customer perceptions of alternative designs. For example, the product design engineer needs feedback to indicate how a prototype design can be changed to elicit the desired customer perceptions.

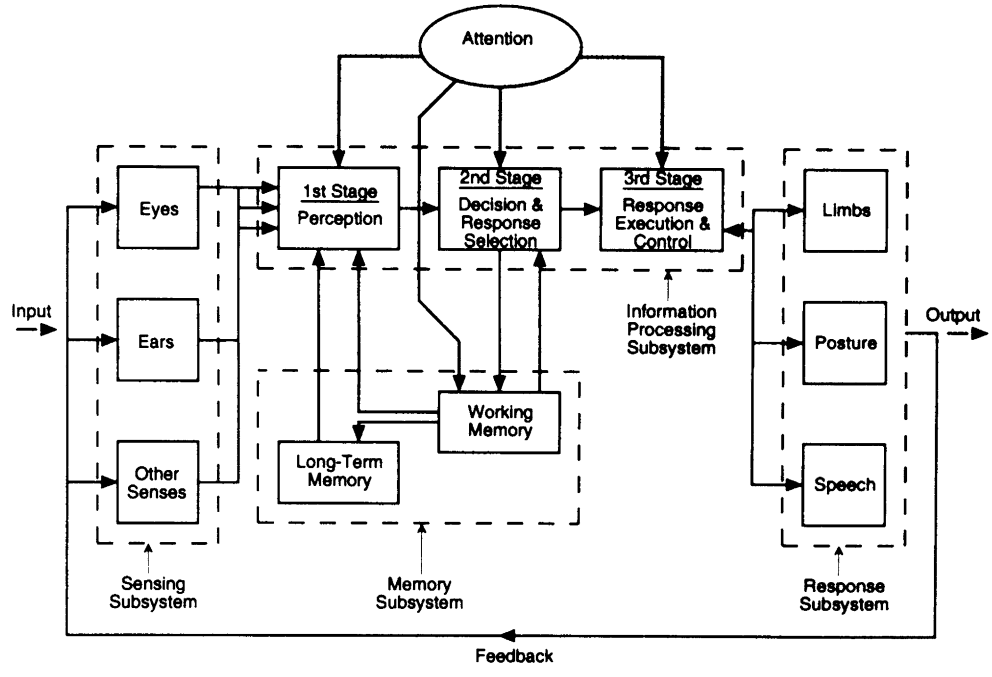
OBJECTIVES

The current research investigates methods for quantifying customer perceptions of vehicle characteristics, with performance feel of the vehicle being an area of special interest. The objective is to develop methods to quantify customer perceptions more quickly, accurately, and efficiently, thereby improving the product design process.

The focus of the research is a literature review addressing three major topic areas. The first topic area is characteristics of human perception in the context of human information processing. The second topic area is existing applications of quantifying perceptions of vehicle characteristics. The last topic area concerns general methods and models for quantifying human perceptions used in the behavioral sciences.

RESULTS

A model of human information processing, shown in the figure below, identifies the components of concern. The role of sensing in perception is described. Limits of sensory detection, discrimination, and absolute judgment are presented. Many aspects of human perception are described in the context of the information processing model. Topics include limitations imposed by the small capacity of short-term memory, effects of learning and expectations upon perceptions, the dynamic nature of the perceptual process, the different perceptual modalities, and preattentive processing and perceptual organization. Selective literature on driver perceptions in a highway safety context is reviewed.



Human Information Processing Model

Five application areas where customer perceptions have been quantified are reviewed. In each area, the methods are described as well as the resulting models and their effectiveness. The five areas are vehicle performance, headlight beam patterns, vehicle interior spaciousness, driver comfort, and vehicle sounds (e.g., starter motor sounds). This material demonstrates the difficulties and challenges of developing methods to systematically incorporate customer perceptions of vehicle characteristics into the design process.

The final area of the research reviews specific methods and models from the behavioral sciences literature for quantifying (i.e., scaling) human perceptions. Key human performance characteristics that influence the scaling task are summarized. A generic model of the scaling process is presented that represents what must occur from when a stimulus, possessing the desired amount of the attribute under study, is presented to a subject to when a numeric value is obtained representing the perceived magnitude of the attribute. The implications of eliciting preferences (i.e., scaling subjects) versus quantifying perceptions (i.e., scaling stimuli) are addressed. Several methods of ordinal scaling and interval scaling are discussed. Each method is described, its strengths and weaknesses noted, and computational issues examined. Example applications are included. Multidimensional scaling is not addressed.

CONCLUSIONS

Efforts to quantify customer perceptions of vehicle characteristics can be very costly and yield results of limited usefulness. The current research reviews alternative methods and models for scaling perceptions, which have the potential to provide more accurate results, with less cost, than some currently used methods. In addition, the research provides design engineers, who may not be familiar with the subject matter, with an introduction to human information processing and perception and with an introduction to previous research on quantifying customer perceptions in an automotive context.

IMPACT

This research can have substantial impact on the methods and models used by automotive companies to quantify customer perceptions of vehicle characteristics. More accurate cus-

tomer perceptions obtained with fewer subjects, and therefore less cost, are clearly possible. Significant opportunity exists for additional applied research.

The material has direct application to any course addressing customer product evaluation as part of the engineering design process. Existing courses in this category at the University of Michigan-Dearborn include Product Design and Evaluation (Industrial and Systems Engineering 549), Total Quality Management (Engineering Management 525), and Vehicle Ergonomics (Automotive Engineering 545).

ACKNOWLEDGMENTS

Andrew Vandecaveye, Ford Motor Company, and Shashank Karnik, a graduate student at the University of Michigan-Dearborn, helped in the initial stages of the project.

REPORT BRIEF

New Algorithms and Software for the Evaluation of Minimum Zone Form Errors

June 18, 1997

STATE OF MICHIGAN RESEARCH EXCELLENCE AND ECONOMIC DEVELOPMENT FUND

SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNERS: State of Michigan
Brown and Sharpe Manufacturing Company

ASSISTANT: Songnian Li
Research Associate

BACKGROUND

Coordinate measuring machines (CMMs) have gained tremendous popularity over traditional hard gauging for dimensional measurement of products on the manufacturing floor. After probing a feature on a part to obtain data points, fitting algorithms are used in assessing feature conformance to form, location, and relational tolerances. CMM manufacturers have developed their own CMM software platforms. In fact, most of the commonly used algorithms in the current commercial software packages for coordinate measuring systems (CMSs) are based on the least squares method (LSM). However, LSM usually overestimates the form tolerances.

Algorithms are recognized as one of the significant uncertainty sources to CMM measurements. Therefore, mathematical definitions of dimensioning and tolerancing principles have been established by a committee from industry and academia, which produced the ASME Y14.5.1M-1994 standard. Accordingly, a number of efforts have been made in order to interpret the standard with practical algorithms and computational methods. These efforts have satisfied the industry for several relatively simple geometric features such as line, plane, and circle. However, a gap still exists between the developed algorithms and the anticipation of industry in regard to universality, accuracy, robustness, and reliability. The effort in this project is one step forward to fill this gap.

OBJECTIVES

The objective of this project is to develop a universal algorithm that has the following advantages over the conventional ones:

- Universality—It should be applicable to general geometric features or elements such as line, plane, circle, cylinder, sphere, cone, etc.
- Accuracy—It must guarantee the minimum zone criterion as given in the ASME standard.
- Robustness and Reliability—The performance of the algorithm and corresponding software are required to be stable when dealing with different tasks where feature parameters and sampling strategy vary, as in the case of a practical situation.

APPROACH

- New mathematical models have been developed to formulate the mini-max problems. A reference feature has been introduced in order to minimize the number of arguments in the objective function. The reference feature is expressed along with specific position vectors in order to improve the convergence performance of the models.
- New nonlinear optimum searching strategies have been proposed to ensure practical accuracy and robustness of the solution of the established models. These strategies are (1) data set reorientation, (2) alternative initialization, and (3) multiple loci strategy.
- A software package has been developed to realize the proposed searching strategies and to guarantee accurate and reliable solutions of the mathematical models. The software is programmed in the C language in the Windows 3.1 operating system. A user-friendly interface was also initialized
- The verification of the conformation of the developed algorithm to the research objective was achieved by means of (1) investigation of objective function images (OFI§); (2) comparison with CMM output, published data, and results out of other algorithms; (3) algorithm testing system (ATS) issued by NIST; (4) computer simulation and statistical analysis; and (5) experiments.

RESULTS

- Formulations: Minimum zone models have been developed that cover the particulars of the form tolerances: straightness of surface line element, straightness of derived median line, flatness, circularity, cylindricity, and sphericity.
- Software package: A user-friendly Windows 3.1 application interface has been initialized.
- Objective function images (OFI§) in relation to different sampling strategies.
- CMM measurement results and reports on planes and cylinders produced by different machining processes.
- Algorithms verification results.

CONCLUSIONS

- By introducing a reference feature and specific points on the feature into the problem formulation, the new minimum zone models have been improved in computability.
- Investigation of OFI helps to determine the computability of the mathematical formulations.
- The presented nonlinear optimum searching strategies are crucial to ensure an accurate and robust searching process and solution.
- The developed mathematical models and computational methods have been verified so that they guarantee the minimum zone criterion. The software package has been proved practical, reliable, and robust.

IMPACT

This research will benefit both the manufacturers and the users of CMMs. The manufacturers of CMM will be able to develop software facing the future generation of CMMs for manufacturing. The users will be able to fit CMM-measured data points to a geometric feature by means of this algorithm to obtain accurate and consistent measurement results that will help them make the right decisions in accepting or rejecting products. The research progress may solve several disputed problems between manufacturing companies, such as Chrysler, Ford, and GM and their suppliers.

ACKNOWLEDGMENTS

The financial support from the Research Excellence and Economic Development Fund (REEDF) of the state of Michigan is gratefully acknowledged and appreciated. The authors also wish to thank Amir El-Baghdady (GSRA) for his efforts to accomplish CMM measurements.

REFERENCES

1. Orady, E. A., Li, S., and Chen, Y., "Minimum Zone Cylindricity Evaluation Using Improved Nonlinear Optimization Method (NOM)," *Transactions of North American Manufacturing Research Institution (NAMRI) of the Society of Manufacturing Engineers (SME)*, Vol. 25, 1997 (accepted for publication).
2. Orady, E. A., Li, S., and Chen, Y., "Minimum Zone Evaluation of Cylindricity Using Nonlinear Optimization Method," *Proceedings of 5th CIRP Seminar on Computer Aided Tolerancing*, 1997 (accepted for publication).
3. Orady, E. A., Li, S., and Chen, Y., "Evaluation of Minimum Zone Straightness by Nonlinear Optimization Method," *Proceedings of 1996 ASME International Mechanical Engineering Congress, Manufacturing Science and Engineering, MED-Vol. 4,* November 1996, 413–423.
4. Orady, E. A., Li, S., and Chen, Y., "A Fitting Algorithm for Determination of Minimum Zone Form Tolerances," *Proceedings of the Society of Automotive Engineers (SAE) IPC'96 Conference*, 1996, 81–87.
5. Orady, E. A., Li, S., and Chen, Y., "Evaluation of Minimum Zone Circularity Using Nonlinear Optimization Techniques," *Proceedings of 1996 Canadian Society of Mechanical Engineering (CSME) Forum,* May 1996, 495–501.
6. Orady, E., Chen, Y., and Ma, C., "Sampling Strategies for Measurement of Circular Features Using Coordinate Measuring Machines (CMM)," *Proceedings of 1996 Canadian Society of Mechanical Engineering (CSME) Forum*, May 7–9, 1996, 488–494.
7. Orady, E., Chen, Y., and Ma, C., "Uncertainty Analysis for Application of CMM in Manufacturing Process," *The Quality and Metrology Symposium,* Bowling Green State University, Bowling Green, Ohio, October 1994.
8. Orady, E., Chen, Y., and Ma, C., "Uncertainty Analysis for the Cylindrical Feature with Application to CMM," *GAGETECH 94 Conference*, October 24–27, 1994, Troy, Michigan.
9. Orady, E. A., Li, S., and Chen, Y., "Uncertainty Analysis for CMM Measurement in Quality Control," *Poster at 1996 Technology Day of UM-Dearborn*, 1996.

Department of Mechanical Engineering

REPORT BRIEF

Dynamic Testing of Composite Drive Shafts

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

Composite shafts are increasing in use for power transmission, particularly in situations where long spans or very high natural frequencies are required. Also, polymeric composite shafts can have strong vibration damping capabilities, which may be useful in relieving some operational noise and vibration problems. However, the free and forced dynamic response of flexible layered composite shafts is complicated by the presence of mechanical response couplings due to material anisotropy inherent in laminated structures. One mechanical coupling found to be significant in composite shafts is bending-twisting coupling. In composite shafts containing certain asymmetries in layering sequence, a lateral force will induce the shaft to respond in bending and twisting. The asymmetry that can produce such an effect is not uncommon. For example, automotive drive shafts comprising an aluminum core wrapped in graphite and e-glass possess this coupling.

OBJECTIVE

In this project, static and dynamic tests have been conducted on composite shafts and compared to numerical results of a mathematical vibration model of a flexible composite shaft.

APPROACH

Experimental and analytical.

RESULTS

Analytical results have been determined on the effects of bending-twisting coupling on shaft vibration. It has been found that neglecting the effect can result in predicted torsional vibration frequencies lower than the actual frequencies by as much as 25 percent.

To verify that bending-twisting coupling has been properly incorporated in the model, a test was devised as shown in Figure 1. In the test, a composite shaft possessing strong bending-twisting coupling was mounted in clamp fixtures and a lateral load was applied. Strain gage rosettes mounted on the upper and lower surfaces were used to determine the shear strain associated with twisting. The graph shows a comparison between the analytically predicted shear strains and the experimental shear strains. Good correlation between the experimental and analytical results are seen, as both follow the same trend.

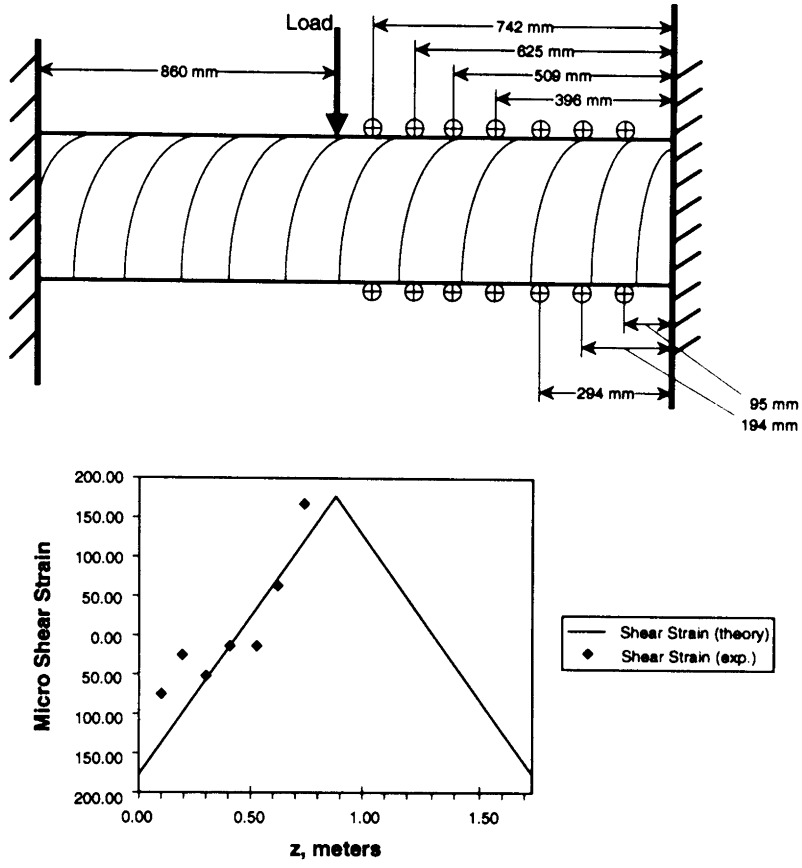

Figure 1

In order to explore the damping capabilities of composite shafts, modal tests have been conducted on three shafts—a steel drive shaft, an aluminum-core shaft wrapped in graphite and e-glass, and an e-glass shaft. In the tests, the shafts were suspended in light elastic cords and modal tests conducted. Modal analysis of the data gave the first three bending natural frequencies (free-free supports) and the associated modal damping ratios. The results are summarized in Table 1. (It should be mentioned that the geometry of the three shafts differ, and so the results thus far should be interpreted as providing only general tendencies.)

	$\omega 1$ (hz)	$\zeta 1$	$\omega 2$ (hz)	$\zeta 2$	$\omega 3$ (hz)	$\zeta 3$
Steel	378.6	0.005297	1157.7	0.034084	1423.4	0.003643
Aluminum/ Graphite/ E-Glass	273.75	0.00721	576.35	0.008843	637.62	0.00905
E-Glass	91.25	0.014405	246.43	0.009541	387.34	0.006065

Table 1

CONCLUSIONS

As expected, the polymeric composite shafts are seen to have higher damping ratios compared to the steel shaft in most cases. The higher damping can possibly result in decreased noise and vibration amplitudes. This notion is being investigated in continuing experiments in which current production drive shafts are being compared to potential re-designs. The configurations of the re-designs are being generated using the mathematical model.

IMPACT

The experimental results and the model can be used to characterize and assist the design of power transmission shafts. The project has led to a master's thesis in the Department of Mechanical Engineering. Some of the results will be incorporated into the department's graduate vibrations and structural analysis courses.

ACKNOWLEDGMENTS

All drive shafts have been donated by General Motors Corporation, Truck Group. Some of the work described here forms part of a 1997 master's thesis in the Department of Mechanical Engineering by Mr. J. R. Yost. The test described in Figure 1 was conducted at General Motors Corporation. Mr. William Danos, an undergraduate research assistant, worked on the project.

REPORT BRIEF

Air- and Structure-Borne Noise Control for Automotive Dampers

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER: Douglas Ronstad, John Pipis, and Richard Gadzala
Tenneco Automotive—Monroe Auto Equipment

ASSISTANTS: Tsung Na
Professor

Tong Ge
Research Associate

BACKGROUND

Research interest in vehicle NVH to improve riding comfort has increased year by year. The air- and structure-borne noise generated by the automotive dampers has become a key factor in evaluating quality of vehicles. In order to improve the acoustic and hydraulic performance of domestic dampers and to increase their market share, a three-year research project focusing on the noise control of hydraulic dampers has been initiated.

OBJECTIVES

1. Construct the parametric fluid dynamic model with advanced CFD computational technology
2. Investigate the mobility of damper enclosures with analytical and experimental modal analysis
3. Develop new NVH strategies to control the air- and structure-borne noise of hydraulic dampers

APPROACH

Technical approaches include: (1) identify the noise sources related to fluid flow; (2) simulate the fluid dynamic behavior inside the hydraulic damper using CFD techniques (ANSYS/FLOTRAN); (3) investigate the interaction of valve and structure, the cause of fluid cavitation and turbulence, and their contribution to overall noise; (4) perform modal analysis of the external structure of the damper; and (5) generate design and development tools and guidelines for engineers.

RESULTS

The following accomplishments have been achieved: (1) A 3D model of the damper piston and valve assembly was developed using the CFD software FLOTRAN of ANSYS. The model was successfully converged. Both pressure velocity distribution plots, which indicate the low-pressure spots for possibilities of cavitations, were generated as shown in Figure 1. This model provides the baseline for further investigation on the flow cavitations, which, it has been concluded, are the main source of air-borne noise. (2) The FEA model of the

damper enclosure, including the double tube, piston and intake valve assembly, base valve, and piston rod, was created using I-DEAS software of SDRC. The fundamental modes and their resonant frequencies were identified for three key piston positions, i.e., full rebound, full jounce, and middle position. The typical bending and shell modes are shown in Figure 2. The experimental modal analysis using SMS-STAR has also been completed.

CONCLUSIONS

FEA and CFD numerical techniques are generally used in order to reduce the high cost required to fabricate many geometrically similar valves. However, a complete physical simulation of a 3D damper is still too complicated to be modeled by any existing codes, even in the most advanced computer. The only alternative is to select a combination of analytical solutions with the results of the FEA/CFD simulations. The overall behavior of the damper can then be derived from the continuity equations.

IMPACT

It is believed that the techniques developed in this project can be easily adopted to other mechanical systems as well as other industry fields. In addition, these technologies and concepts can be integrated into our engineering curriculum as advanced thesis topics on vibration and acoustics. Both impact and random excitation methods will be implemented as a case study in the course ME 346, Instrumentation and Measurement. The modal parameters, i.e., resonant frequencies, damping ratios, and mode shapes of different dampers, will be determined. These experimental results will be used to compare with and validate the analytical results from the FEA model developed in the project as presented in the previous sections.

ACKNOWLEDGMENT

This project is jointly sponsored by Monroe Auto Equipment and the University of Michigan-Dearborn. The authors are very much in debt for the support received from Dr. Sengupta, director of the Center for Engineering Education and Practice (CEEP), and Mr. Doug Ramstadt, supervisor of research and development, Monroe Automotive Equipment. In addition, engineers from Monroe have contributed significantly to the project: John Pipis developed the 3D CFD model and conducted many test runs, and Rich Gadzala assisted on the NVH tasks and FEA model developments as well as on test method improvement and test facility designs.

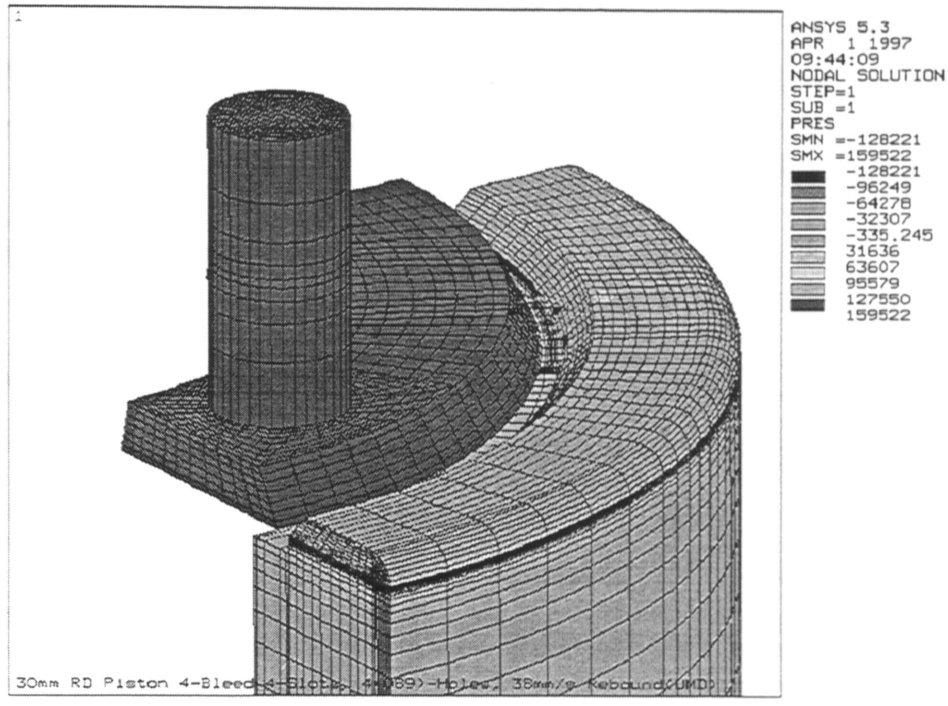

Figure 1. 3D-CFD Pressure Distribution Contour in ANSYS 5.3

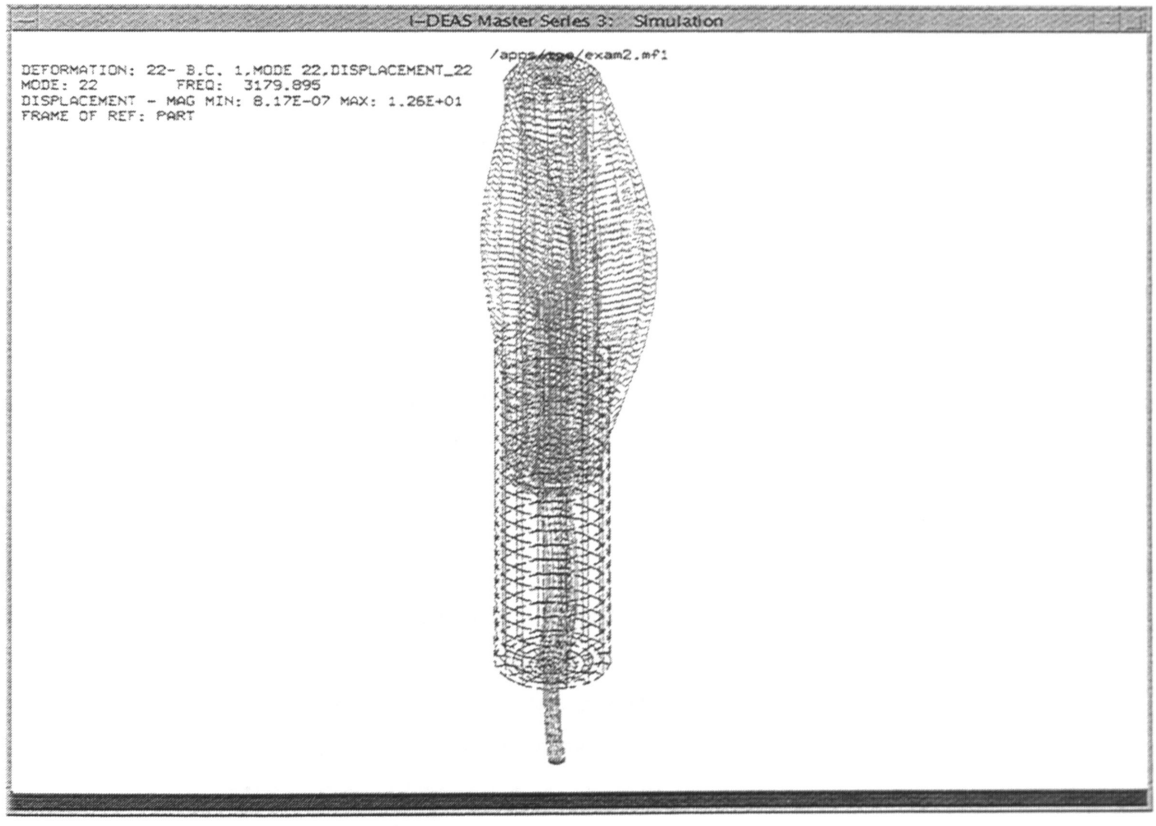

Figure 2. 3D-FEA Modal Shape in IDEAS-Master Series 3.0

REPORT BRIEF

Fatigue Damage in Solder Joints under Thermomechanical Loading

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Mechanical Engineering

PARTNERS: Eliot Fang, Paul Taylor, Michael Neilsen, John Aidum, and Yi-Hsin Pao

ASSISTANT: Fan Yang
Research Associate

BACKGROUND

The Sn-Pb eutectic alloy is widely used as a joining material in the electronics industry. In this application, the solder acts as both electrical and mechanical connection within and among the different packaging levels in an electronic device. Advances in packaging technologies driven by the desire for miniaturization and increased circuit speed result in severe operating conditions for the solder joint, thus leading to solder joint reliability problems. Specifically, the mismatched thermal expansion characteristics of the materials joined by the solder and the cyclic temperature fluctuations normally encountered during service constitute a condition of thermomechanical loading for the constrained solder. The reliability of solder interconnections under thermomechanical fatigue (TMF) becomes more critical as new electronic packaging technologies evolve.

OBJECTIVES

The primary objective of this research project is to develop a comprehensive mechanics approach capable of predicting the integrity and reliability of solder joint material under thermomechanical loading. The methodology is based on a state-of-the-art technology of damage mechanics, which leads to a macroscopic description of the successive physical deterioration phenomena.

APPROACH

A new theory of **Damage Mechanics** has recently emerged and reached its maturity to solve a wide range of engineering design analyses. This theory can take into account the degradation of material properties at the microstructure level to be analyzed with continuum mechanics theory. The fatigue damage in solder joint material is ideally suited for characterization by the new theory.

RESULTS

The following results have been obtained:

1. Development of fatigue damage model—isotropic damage and anisotropic damage
2. Determination of static damage variables (Figures 1 and 2)
3. Effect of strain rate on stress-strain diagrams (Figure 3)
4. Determination of fatigue damage variables
5. Determination of fatigue endurance limit
6. Validation of fatigue damage model under unidirectional fatigue load (Figure 4)
7. Validation of shear damage

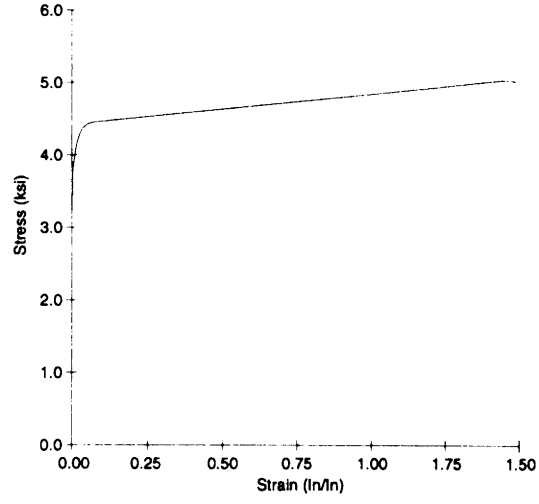

Figure 1. Stress-strain curve for $1x10^{-3}$ S^{-1}

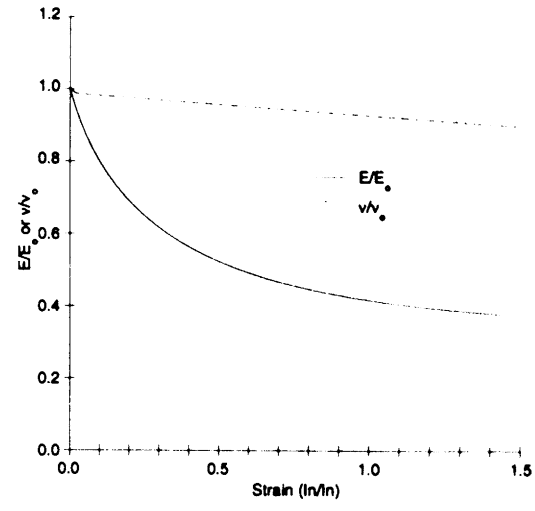

Figure 2. Variation of E/E_o and v/v_o with strain

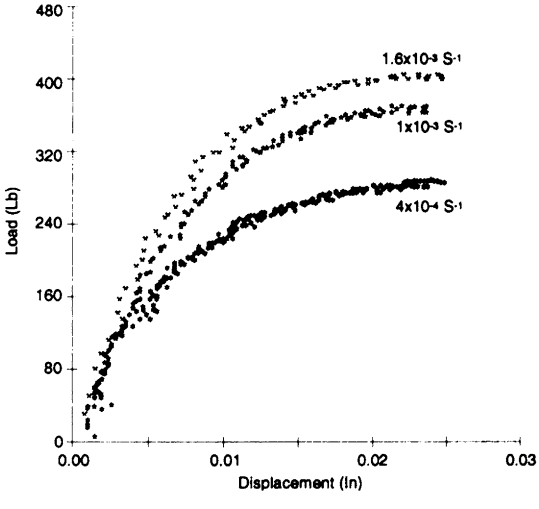

Figure 3. Load-displacement curves at 3 rates

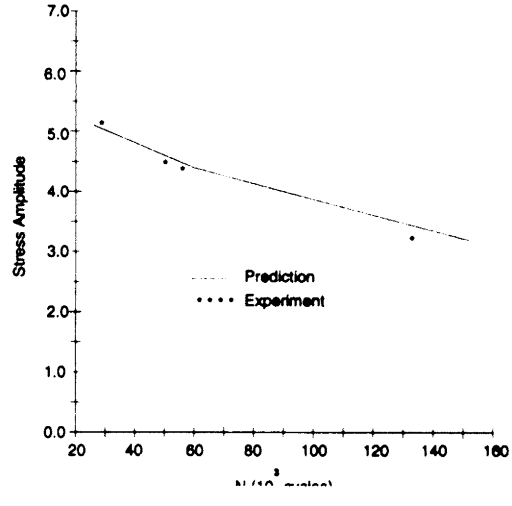

Figure 4. Fatigue life with constant amplitude cycling

CONCLUSIONS

The project entails a comprehensive investigation of thermo-mechanical loading of solder joints. A new anisotropic damage model particularly developed for the solder joint material is presented. The model is able to offer an expedient numerical simulation of solder joints observed in electronic devices.

A test program to determine the necessary damage variables and their evolution equations under TMF condition has been performed. In addition, an investigation to examine the effect of mean stress on the solder-joint material has been carried out. It is concluded that the effect of mean stress on fatigue life on the solder material is insignificant when applied mean stress is lower than 0.5 ksi. The effect, however, becomes significant when the mean stress exceeds 1.0 ksi. In order to determine the threshold point of fatigue damage development, a series of fatigue tests has been conducted to determine endurance limit. At 10^6 cycles, the measured stress at the endurance limit is 2.35 ksi.

IMPACT

The theory of damage mechanics has not been taught as a subject in either undergraduate or graduate courses. Because of the importance of this subject matter, an attempt will be made to introduce it, for the first instance, at graduate level. On the industrial side, a research project has been funded by the Sandia National Laboratories to conduct fatigue damage analysis of solder joints without temperature effects.

REPORT BRIEF

Heat Transfer Augmentation in Natural Convection Using Microencapsulated Phase Change Materials

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER: Trilochan Singh
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BACKGROUND

Rapid advances in solid state physics and today's high-performance VLSI technology have resulted in extremely high module-level heat fluxes. In fact, one of the most important variables limiting the performance of electronic chips is the heat-removal rate. As a result, efficient thermal management of electronic packages is crucial to their optimum performance. The need of the day is a working fluid that enhances heat transfer while maintaining the fluid's electrical inertness.

This cannot be accomplished by any known single-phase fluid because electrical and thermal properties are closely related and increasing one would inherently cause an increase in the other. It is therefore imperative to design an additive phase that, while augmenting the thermal properties, does nothing to diminish the essential electrical inertness of the base working fluid.

One innovative way to accomplish this is to use phase change materials (PCMs) encapsulated into microscopic packets and suspended in a working fluid. This way, the PCM can augment heat transfer by effectively increasing the specific heat of the resulting slurry, while the resinous encapsulating shell of the microcapsules maintains the electrical barrier between the two working phases.

OBJECTIVES

The prime objective of this work was (a) to perform a parametric study in heat transfer augmentation in natural convection in a rectangular cavity using PCM slurries and (b) to isolate various design parameters in designing such heat transfer augmenting fluids.

APPROACH

The experimental approach consisted of suspending microcapsules of two chosen PCM materials (palmitic acid 30 μm capsules and myristic acid 100 μm capsules—Figure 1) in water and silicone oil, respectively. The resulting slurries were then used (separately) as the working heat transfer fluid in the rectangular cavity described in Figure 2[1]. The technique used for manufacturing these capsules is termed *coacervation*. The PCMs and suspending fluids were chosen after careful density matching considerations, which ensured that the

[1] Convection in cavities could be from being heated from below or being heated from the side. The former, often termed as Rayleigh-Benard convection, was the configuration chosen for the present study.

capsules would rise and fall in the working fluid as their cores melted or froze, thereby constantly thermally cycling the PCM material.

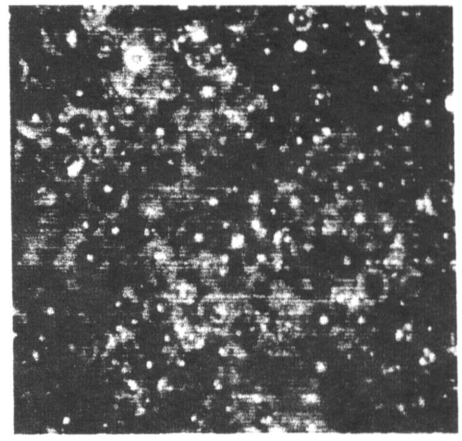

Figure 1. Sample photograph of microcapsules.

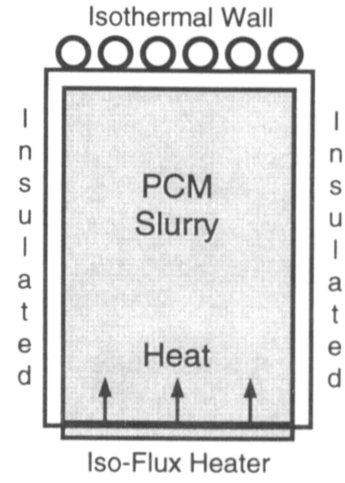

Figure 2. Schematic of the test section.

The non-dimensional parameters investigated were the Rayleigh number "Ra" (which quantifies the intensity of convection in natural convection problems), the Stefan number "Ste" (which quantifies the latent heat contribution, as compared to the sensible heat of the slurry), and the sub-cooling ratio "T_{scr}" (quantifying the effect of sub-cooling below the melting point of the PCM). Each parameter was varied in isolation by varying either the enclosure height (Ra), the particle concentration (Ste), or the cold wall temperature (T_{scr}).

RESULTS

After conducting four sets of experiments (maximum volumetric concentration of 4 percent in any experiment) in which the above-listed parameters were studied, the results were analyzed. The analysis reveals many interesting findings.

The experiments with water as the suspending fluid did not yield any augmentation in the heat transfer (Figure 3). While in principle the addition of a phase change material that is being constantly thermally cycled would suggest an enhancement, the fact that the thermal properties of water are superior to those of the capsules used ($K_{water}/K_{palmitic\ acid} \sim 3.8$, where K is the thermal conductivity) reduces the possibility of the capsules participating in the heat transfer, since most of the heat would evade the particles in finding the path of least resistance through the fluid. In fact, 2–4 percent concentrations of particles at lower Rayleigh numbers produced a detriment in the heat transfer rate.

In addition, the palmitic acid microcapsules were poorly manufactured and had a significant amount of clumping (up to a few mm in diameter). Clumping of this nature increases the diffusive time that the heat takes to reach the center of the capsule core. Hence, a large part of the PCM would remain an inactive participant in the heat transfer even if some of the heat did penetrate the capsule.

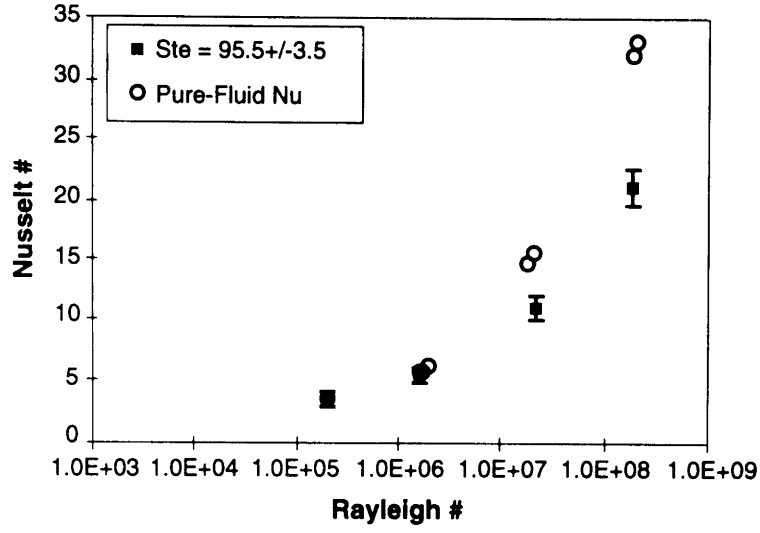

Figure 3. Heat transfer detriment when using water and palmitic acid microcapsules.

The experiments with myristic acid microcapsules suspended in silicone oil (K_{water}/ $K_{palmitic\ acid}$ ~ 1.0, Figure 4), on the other hand, produced significant enhancements in the heat transfer (over 50 percent). Concentrations ranging from 0.5 to 2 percent show the largest augmentation. In spite of careful density matching and the use of small quantities of surfactants to ensure that there was no coagulation or clumping of the particles, some experiments using a 4 percent volumetric concentration of particles did show significant amounts of clumping. For the ranges investigated, the sub-cooling ratio did not have any significant effect on the heat transfer.

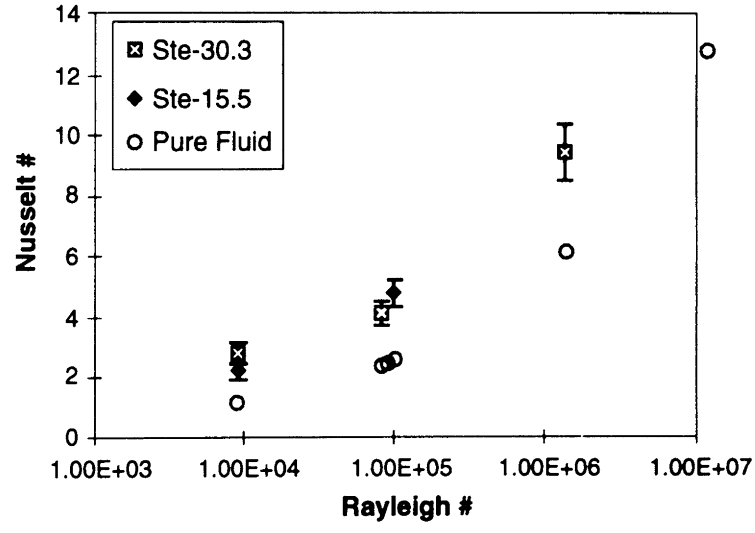

Figure 4. Heat transfer enhancement when using silicone oil and myristic acid microcapsules.

CONCLUSIONS

A study for investigating natural convection heat transfer using PCM slurries was conducted in a rectangular cavity. It was observed that:

1. Heat transfer augmentation using PCM slurries is indeed possible.

2. Heat transfer augmentation using PCM slurries is not always feasible.
3. The ratio of the thermal properties of the two phases is an important parameter in the transport.
4. Sub-cooling does not have any significant effect on the augmentation.

IMPACT

Recent trends in the electronic industry show a surge in VLSI technology and micro-mechanical devices with very high heat generation rates. The use of PCM slurries promises to be an effective technique for enhancing the heat transfer rate in such electronic cooling applications.

REPORT BRIEF

Design and Assembly of Polymeric Structural Components

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER	Currently being sought
ASSISTANT	Wade Johnson Undergraduate student, Department of Mechanical Engineering
ASSOCIATE	William K. Waldron, Jr. System Dean, Engineering Division, Baker College, Flint, MI

BACKGROUND

From preliminary calculations to finite-element analysis, much of the engineering design process depends on reliable models for predicting the stress-strain response of materials under loading. For many structural situations, the behavior of metals is well understood and accepted stress-strain models are available. With these models, accurate computer-aided analysis is carried out, which minimizes the need for prototyping and reduces design time and cost.

Polymeric materials (plastics) are light in weight, easy to form, and relatively inexpensive. They have long been widely used for non-load-bearing applications such as casings and automotive trim. Plastics now also see increasing use in structural applications, requiring more accurate modeling and computer analysis for design. The response of plastics, however, is fundamentally different from that of metals. It is inherently time-dependent and generally much more sensitive to temperature than the response of metals. Response models for these materials require consideration of these differences.

Currently available stress-strain-time-temperature relations for plastics, unfortunately, are not generally satisfactory. For low-stress or small-deformation situations, engineers often use equations for metal elasticity or linear viscoelasticity, which are invalid for analysis of large deformations. The theory of nonlinear viscoelasticity can predict response in this range, but models call for material parameters that are too numerous or difficult to measure experimentally.

OBJECTIVES

To improve design, forming, and assembly processes with plastics, new stress-strain-time-temperature models are needed. The models should be valid over large ranges of temperature and fully three-dimensional deformation and include yield, post-yield behavior, and permanent set effects. It is the goal of this project to develop a model that satisfies these requirements and that calls only for material parameters available from relatively simple tests.

APPROACH

Published data are available (G'Sell and Gopez 1985) of stress-strain response of polycarbonate in constant strain-rate tests under plane simple shear at a variety of temperatures.

They indicate two distinct stages of homogeneous deformation: approximately linear initial response at small shear; and a second stage at very high (post-yield) shear where the stress-strain curve is again linear, although much less steep. For intermediate levels of shear, however, measurement is unavoidably complicated by the initiation of shear banding at the center of the specimen. Only when the banding has propagated throughout the specimen can homogeneous response again be evaluated.

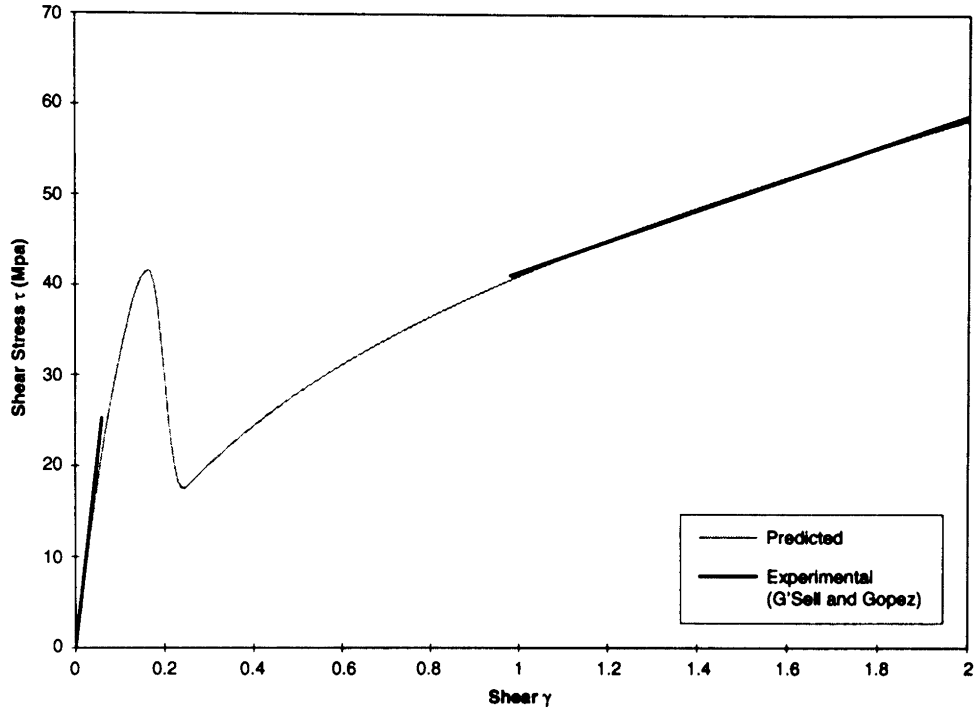
Under a sustained constant load, polycarbonate shows increasing deformation (creep) to the point of ultimate failure. This material can thus be described most generally as a viscoelastic fluid. The Maxwell model, the simplest linear stress-strain-time relation available for this class of material, has been used to fit the linear portions of the measured stress-strain curve for polycarbonate at room temperature. To bridge the gap between these portions and create a single representation for all levels of shear, a new constitutive equation (Huntley, Wineman, and Rajagopal 1990, 1992) has been used. This equation assumes that yield and early post-yield behavior are driven by a continuous process of microstructural transformation comprising rearrangements of entanglement networks and phase changes in polymer macromolecules. The transformation process is assumed to follow a normal energetic distribution about a mean state of deformation. This framework accounts not only for yield, but also for permanent set after the release of load and recovery of viscoelastic deformation.

The model will be extended into a fully three-dimensional stress-strain-time relation through the use of simplified forms of Beatty-Blatz-Ko response for the initial and post-yield stages. Temperature dependence will then be implemented through the time-temperature superposition. The final model will satisfy all mathematical requirements for a three-dimensional finite-deformation constitutive equation, yet offer greater utility in that the number of parameters to be determined experimentally is held to comparatively few: characteristic relaxation time, Young's modulus and Poisson's ratio for the initial and post-yield stages of deformation, and a single rate parameter controlling the transformation process. These values can be extracted from published data for polycarbonate or from uniaxial tension tests for other materials.

Once the full three-dimensional model is developed, it will be tested in finite-element simulations of simple forming processes with polycarbonate, such as cold bending of sheet stock. The simulations will be compared with experimental measurements. Permanent set and springback will be predicted.

RESULTS

Work completed to date has established proof of concept (see figure below). The figure shows shear stress vs. shear deformation. The two experimentally measured homogeneous response stages in simple shear appear as heavy straight lines and the predicted response curve as a lighter line. Agreement is very good. Furthermore, the model predicts a yield spike and subsequent drop in stress that corresponds qualitatively with observed yield.



Shear Stress vs. Shear Deformation

A manuscript entitled "A Two-Phase Model for the Nonlinear Viscoelastic Response and Plastic Behavior of Glassy Polymers" is currently being prepared for publication.

IMPACT

Improved prediction of the behavior of engineering plastics in general three-dimensional deformation and at various temperatures will have direct impact on the accuracy and efficiency of design and fabrication as well as processing of these materials. A simple example is the cold bending of plastic sheets mentioned above: to form a right-angle elbow by bending at a certain rate, how far past perpendicular must the stock be bent in order to account for elastic springback and viscoelastic recovery? Another example involves temperature effects: if a plastic radiator mount is to be installed in a vehicle and loaded before baking in a paint oven, how must the original part be designed if it is to have a prescribed shape after baking?

A description of this project is being included as a case study in a new graduate course currently under preparation, "Nonlinear Mechanics of Solids."

REPORT BRIEF

Development of Thermoplastic Composite Stamping Processes for Automotive Applications

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Mechanical Engineering

PARTNERS: Paul Daly, Siemens Automotive
Jay Pyper, Allied Signal Plastics

ASSISTANT: Z. Xia
Visiting Research Scientist

BACKGROUND

Thermoplastic matrix composites have several advantages over thermoset matrix composites, such SMC and SRIM. Thermoplastic matrix composites have higher fracture toughness and damage tolerance. They can be recycled. In general, processing time for thermoplastic matrix composites is faster than that of SMC or SRIM composites. Furthermore, they can be post formed and joined by welding. With all these advantages, they appear to have a bright future in many automotive applications, particularly in body and chassis components. However, processing methods to produce such components in thermoplastic matrix composites need to be developed before they find wider applications. Press forming or stamping is one of the processing methods that have a great appeal to the automotive industry, since stamping is already used for metals and stamping presses used for metals can be easily changed over to stamp composite parts. There is already a great deal of knowledge and data base for metal stamping, but similar information has not been developed for thermoplastic matrix composites.

OBJECTIVES

The objective of this research is to develop innovative press forming techniques for thermoplastic matrix composites that have the potential for applications in engine intake manifolds, lower control arms, and other structural automotive applications.

APPROACH

The approach used in this project can be divided into three steps:

1. Conduct press forming operations and develop processing window
2. Determine processability and measure the properties of the formed parts
3. Determine the material characteristics during forming and develop analytical models for the press forming process as it applies to thermoplastic matrix composites

RESULTS

Allied Signal has provided us with several extruded unfilled and filled nylon 6 sheets to conduct press forming experiments. The filled materials contain either 33 wt.% short glass fiber or 25 wt.% mineral plus 15 wt.% short glass fiber. The sheets were supplied in two different thicknesses. A two-piece aluminum mold was designed (Figure 1) and built in full consultation with Siemens Automotive. Sheets of the size of 254 mm x 254 mm are being clamped in a square metal frame and then heated in an air-circulating oven before being

placed in the bottom mold cavity. Both top and bottom mold cavities are preheated prior to placing the sheet in the mold. The press is closed and held in that position for a predetermined amount of time. After the press is opened, the formed part is allowed to cool outside the mold before taking it out of the frame.

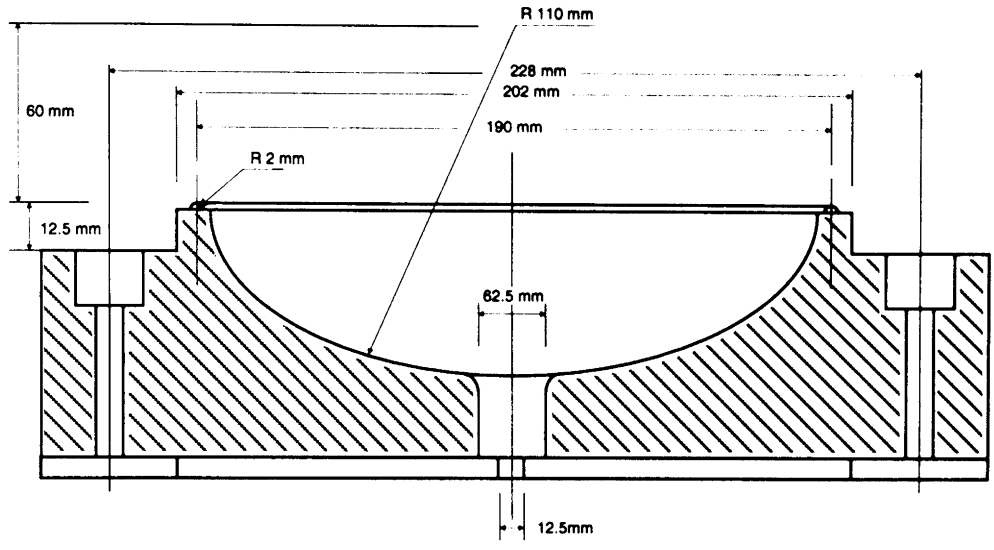

Figure 1. Schematic of the lower half of the mold used in press forming.

Forming experiments have been conducted with various oven temperatures (which control the sheet temperature), press temperatures, mold closing speeds, and molding pressures. The unfilled sheets can be formed with no difficulty in both thicknesses; however, 33% glass filled sheets tend to crack at the crown as they are formed. The 25% mineral/15% glass filled sheet can be formed in thinner gages, but the thicker gages show a tendency to crack. Further studies are being conducted to determine the processing window for all three materials.

CONCLUSIONS

This project is in the preliminary stages of its execution; the principal reason for the delay is the time lost due to renovation in the *Plastics and Composites Processing Laboratory* in the summer of 1996. However, several conclusions can be made from the work done so far. We have demonstrated that nylon sheets can be press formed in both unfilled and filled conditions; however, process parameters, which include sheet temperature, mold temperature, pressure etc., are different for the unfilled and the filled materials. We are currently determining these process conditions; however, like the metal stamping technology, process models should be developed to predict these conditions prior to molding.

IMPACT

This project will have great impact on the current plastics and composites manufacturing course (ME 484). Press forming will be used as one of the experiments in the laboratory part of this course. It may also be used as demonstration in a graduate-level automotive composites manufacturing course, which will be developed in the near future.

As for the impact on industry, both Siemens Automotive and Allied Signal have shown a great deal of interest in this project. Siemens Automotive is interested in finding out if thermoplastic composite stamping can be used to produce engine components replacing more expensive injection molding process. Allied Signal has shown interest, since nylons have not been used in the press forming process before and they see it as a relatively inexpensive process for making structural components.

ACKNOWLEDGMENT

Acknowledgments are due to both Siemens Automotive and Allied Signal for their support on this project. Allied Signal has given a gift of $10,000 as partial support of this project. Allied Signal is also providing the material for the press forming trials. Siemens Automotive has also provided financial support through CEEP. Furthermore, they are testing some of the formed parts for their weldability.

REPORT BRIEF

Development of a Controlled Atmosphere Brazing (CAB) Furnace Thermal Model

June 18, 1997

STATE OF MICHIGAN
RESEARCH EXCELLENCE AND ECONOMIC DEVELOPMENT FUND
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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ASSISTANT: Karthik V. Kumar
Graduate Student Research Assistant

BACKGROUND

A brazing furnace is a furnace used to braze (i.e., join) different components to form one single component. The brazing process involves joining two or more metal components using an alloy of the metal involved, the melting point of which must be lower than that of the metal components. The different components along with the brazing metal are heated in the furnace to a temperature equal to the melting-point temperature of the brazing metal. The melted brazing metal fuses with the components on cooling. The brazing process can take place in a vacuum or in a controlled atmosphere. In the controlled atmosphere brazing furnace, nitrogen is used. Nitrogen forms a blanket over the assembly and protects it from oxidizing. Oxidizing of the metal and/or the metal alloy prevents effective brazing. For effective brazing, the temperature in the furnace should be controlled properly, so that there is sufficient heat transferred to the assembly (heat exchangers) to be brazed. In order to evaluate effective brazing, a numerical simulation of the heat transfer between the furnace and the heat exchanger is needed. A program is developed to perform this numerical simulation. The result of the simulation is the thermal model.

The thermal model is part of a larger-scale project to implement fuzzy logic control in the current CAB process. Dr. George J. Vachtsevanos of Georgia Tech is currently designing a control algorithm for the furnace. The algorithm's architecture is presented in Fig. 1. The thermal model is shown in the figure, providing predicted heat exchanger temperature profiles to several controllers. Through the integration of the thermal model and the control system the process will provide quality parts with flexibility in manufacturing.

OBJECTIVES

The objective of this project is to develop a thermal model of the CAB furnace for the current product mix that optimizes heat exchanger quality while providing flexibility for manufacturing.

APPROACH

The CAB thermal model will be developed by modifying an existing vacuum furnace thermal model. The vacuum furnace has been previously used in the automotive industry for brazing heat exchangers. An existing thermal model, Thermal Analyzer [2], had been

developed for this process. Figure 2 shows the current algorithm architecture. Heat exchanger and furnace geometry data, in a file called "in.dat," are input to a subroutine RAVFAC [3]. RAVFAC calculates the radiation viewfactors, which are then passed to subroutine SERA where heat fluxes are calculated. The heat fluxes are passed to LURN, which ultimately determines the heat exchanger temperature profile. Development of the CAB thermal model will use the same architecture. Modifications will involve adding convective heat transfer, developing new geometry input files, and adding pre- and post-processing capabilities. The vacuum and CAB thermal models will be validated with data from existing furnaces as well as a new experimental furnace currently being designed and built by Ford Motor Company.

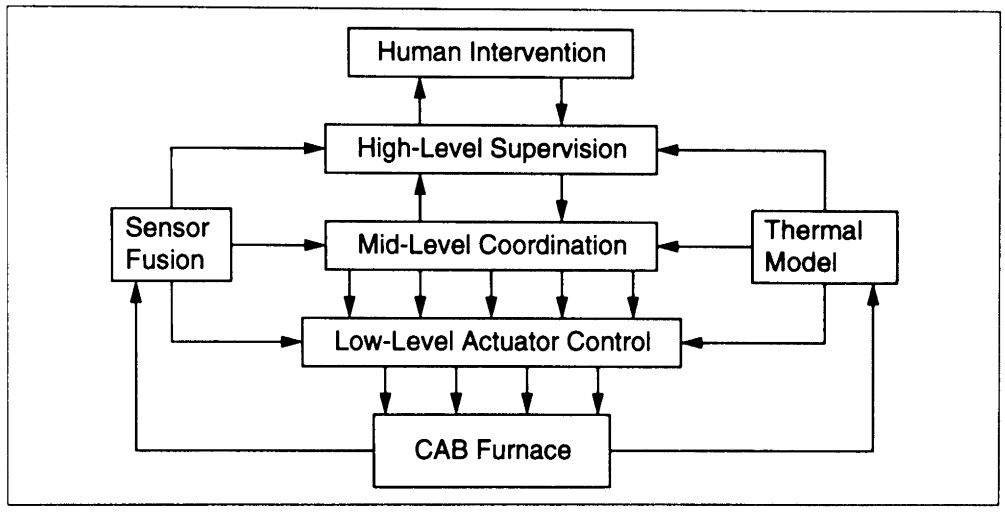

Figure 1: The Control Algorithm Architecture of the CAB Furnace [1].

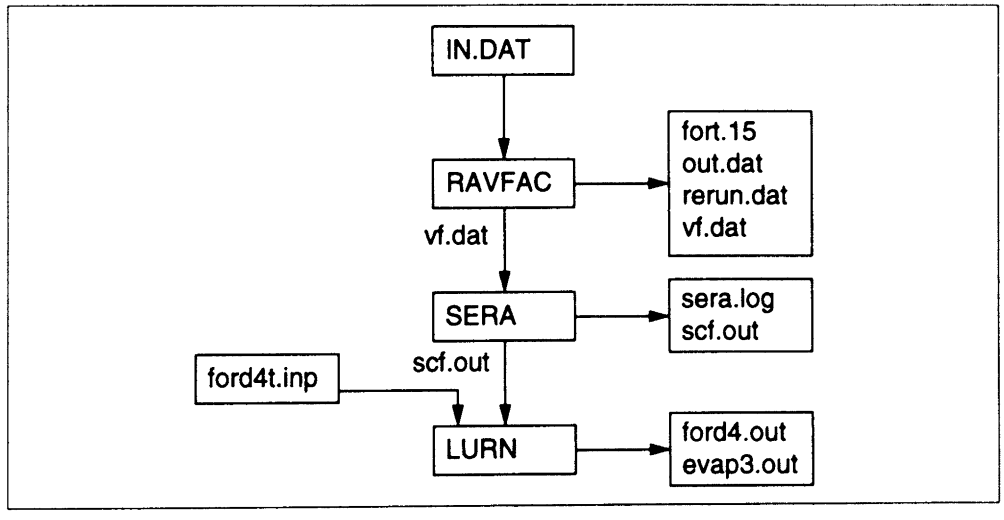

Figure 2. Flow Chart Illustrating the Program and Sub-Program with Their Input and Output Files

RESULTS

The result of the effort will be a validated working thermal model that will predict transient heat exchanger temperature profiles during the CAB manufacturing process.

IMPACT

The thermal model will be an integral part in improving CAB technology. It is part of a next generation CAB furnace project that will improve the process worldwide in terms of productivity and quality of the manufacturing operation.

ACKNOWLEDGMENT

This project is supported through a grant from the Research Excellence and Economic Development Fund of the state of Michigan and through Climate Control Operations, Ford Motor Company.

REFERENCES

1. Vachtsevanos, G. J., Smith, M. H., Pirovolou, D. K., Huber, A. M., and Henry, V., "A Neuro-fuzzy Approach to Stabilization of Glass Fabrication Processes," *Proceedings of the 29th Symposium on Automotive Technology and Automation*, Florence, Italy, June 1996.
2. Pond, J., "Thermal Analyzer Program," Remtek Corporation, 1991.
3. Lovin, J. K. and Lubkowitz, A. W., "User's Manual for 'RAVFAC': A Radiation View Factor Digital Computer Program," NASA Technical Report, NASA CR-61321, November 1969.

REPORT BRIEF

Entropy Generation in an Automotive Refrigeration System

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER: Climate Control Operations, Ford Motor Company

ASSISTANT: Paul Rogers
Research Assistant

BACKGROUND

Efforts have been made to improve air-conditioning efficiency by methods of refrigerant control. Control can improve efficiency only by reducing losses within the system during operation. The magnitude of the improvement can be estimated only by knowing the magnitude of the individual losses within the system. Therefore there is a need to determine the magnitude of individual losses.

OBJECTIVES

The objective of this project was to identify the significant losses in the current cycling clutch-orifice tube (CCOT) refrigeration system, quantify them, and suggest a course of action to improve overall performance.

APPROACH

A Lincoln Mark VIII's air-conditioning system was instrumented with sensors to measure refrigerant temperatures and pressures and air temperatures, pressures, and relative humidities. The vehicle was driven steadily. Data were collected for several operating conditions. idle, 30 mph, and 60 mph. The data were processed to determine energy and entropy transfers during periodic steady state. Ultimately, entropy generation of the system components were calculated and compared. Entropy production was compared between components for the same operating condition and compared for one component between different operating conditions.

RESULTS

Figure 1 shows the comparative losses between components at 60 mph. As expected, the compressor losses were the largest, followed by the condenser and evaporator losses. The losses of the expansion device were small in comparison to the other losses.

In addition to this calculation and comparison of entropy losses, a refrigerant property program was developed that will be used for continuing research in modeling the refrigeration system. The software calculates temperature, pressure, density, internal energy, enthalpy, and entropy. Given any of the two latter independent intensive properties, the program will return with the value of all other properties. The program was written to determine the properties of any refrigerant. Currently the program can handle R-134, R-12, and R-502. With a simple data file of any pure, simple, compressible fluid, the program can determine the fluid's thermodynamic properties. The program accuracy is dependent on the equation of state. This program is based on the Martin-Hou equation of state.

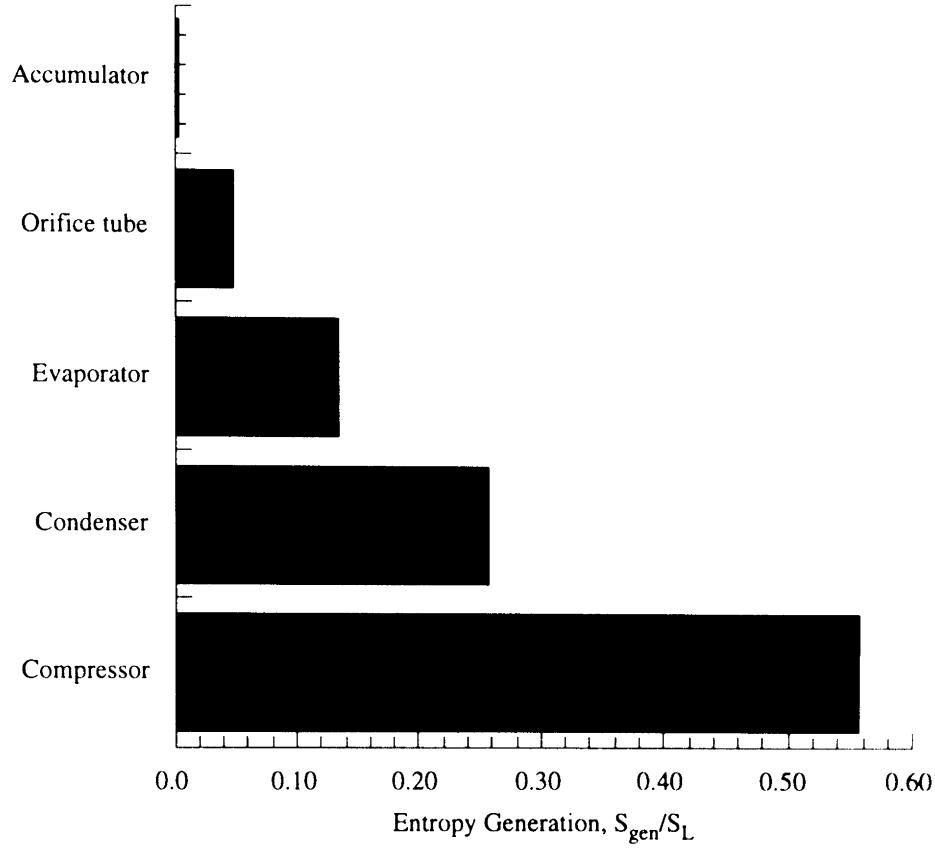

Figure 1: Percentage of the total entropy generated for each component of the system.

CONCLUSIONS

Improving the refrigeration system during periodic steady state obviously can be significantly improved by reducing losses within the compressor. Losses within the compressor itself should be identified and quantified.

IMPACT

This research has had impact on undergraduate and graduate education through the development of the refrigeration software as well as the research. The concepts of refrigerant modeling have been integrated into the mechanical engineering curriculum. In the undergraduate course Applied Thermodynamics, ME 330, students are required to write a numerical code to calculate the latent heat of vaporization as one of their laboratory assignments.

In addition, the experimental research has supported the graduate student in terms of equipment and a topic. It has also supported undergraduates in terms of summer employment.

REPORT BRIEF

An Investigation of Flame Development and Burn Duration in a Lean-Burn Natural Gas Engine

June 18, 1997

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
SCHOOL OF ENGINEERING, UNIVERSITY OF MICHIGAN-DEARBORN

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Research Assistant

BACKGROUND

The wider flammability limit of natural gas-air mixtures offers potential for operating spark ignition (SI) engines on lean air-to-fuel ratios. This helps to reduce exhaust gas emissions, particularly oxides of nitrogen. In spark ignition engines operated at very lean air-to-fuel ratios, however, the development of the initial flame kernel and its subsequent propagation becomes highly sensitive to the physical and chemical state of the mixture. This can lead to an unstable burning process, which can adversely affect engine performance and lead to increased hydrocarbon emissions, unsteady power output, and unacceptable engine operation. To avoid these conditions it is necessary to enhance the burning process and properly calibrate and control engine fuel and ignition management systems. This requires knowledge and understanding of relationships between mixture quality and flame initiation and its propagation in the combustion chamber of SI engines.

OBJECTIVE

The objective of the investigation was to determine the relationship between the initial flame kernel development and the rapid burn period under different equivalence ratios and engine operating parameters and to assess the impact of lean-burn operation on the burning process. The information would be useful to engine designers and calibration engineers to control and optimize lean-burn engine performance.

APPROACH

The experimental part of the work was conducted on an 8-cylinder, 4.6 liter, SI engine. The engine was equipped with a sequential type gaseous fuel injection system. An external controller was used to control air-to-fuel ratio (A/F ratio and equivalence ratio) and ignition timing. A UEGO sensor, calibrated for natural gas, was used to monitor A/F ratio and its variations on line as tests were being conducted. A Kistler pressure transducer was mounted flush in the cylinder head of cylinder No. 1. Cylinder pressure was recorded at every half-degree interval and was stored in a data acquisition system along with other engine design and operating parameters. The cylinder pressure-time data, averaged over 300 consecutive cycles, was used to estimate the mass-burned fraction at different intervals and engine operating conditions. The mass-burned fractions were corrected for heat losses to the cylinder walls using Woschni's heat transfer relationship. Tests were conducted at steady state at different engine loads (bmep 150–550 kPa), speeds (1500–3500 rpm), equivalence ratios (0.6 to stoichiometric), and spark timings.

RESULTS

The dependence of initial flame development time, defined as the crank angle for 10% mass-burned fraction, on equivalence ratio is shown in Figure 1 for an engine operating at

2100 rpm and 250 kPa bmep. The flame development time is not affected by equivalence ratio (Φ) until the latter reaches a value of about 0.8. As the mixture gets leaner beyond Φ = 0.8 the development time increases rapidly. This necessitates advance in MBT timing, as shown in the figure. Once the flame front has been developed its subsequent propagation, defined in terms of rapid burn duration, depends on equivalence ratio, as shown in Figure 1 (rapid burn duration is defined as the time for 10%–90% mass-burned fraction). The normal burn-ing velocity of the natural gas-air mixture decreases rapidly as the mixture equivalence ratio is reduced. This is reflected in increase in rapid burn duration. The difference in rapid burn duration between ignition occurring at MBT and at 30 degrees BTDC was found to be very small. The significant difference in combustion duration in a lean-burn natural gas engine arises in developing a stable flame front, as shown in the figure.

Figure 2 shows the effects of ignition timing (and hence cylinder pressure and temperature) on initial flame development time and rapid burn duration. Increase in flame development time with advanced timing arises due to lower average gas temperature in the cylinder than when the timing is retarded. On the other hand, retarded timing lowers the fresh mixture temperature and prolongs the rapid burn period well into the expansion process. Increasing the mixture equivalence ratio helps to reduce both, as shown in the figure.

The flame development results were correlated with the thermodynamic state of the mixture at ignition. Figure 3 shows the correlation between the flame development time and predicted mixture temperature at ignition. Similar trends were obtained at other power levels and engine speeds. The information can be used to develop a full correlation between the flame development time and engine design and operating parameters.

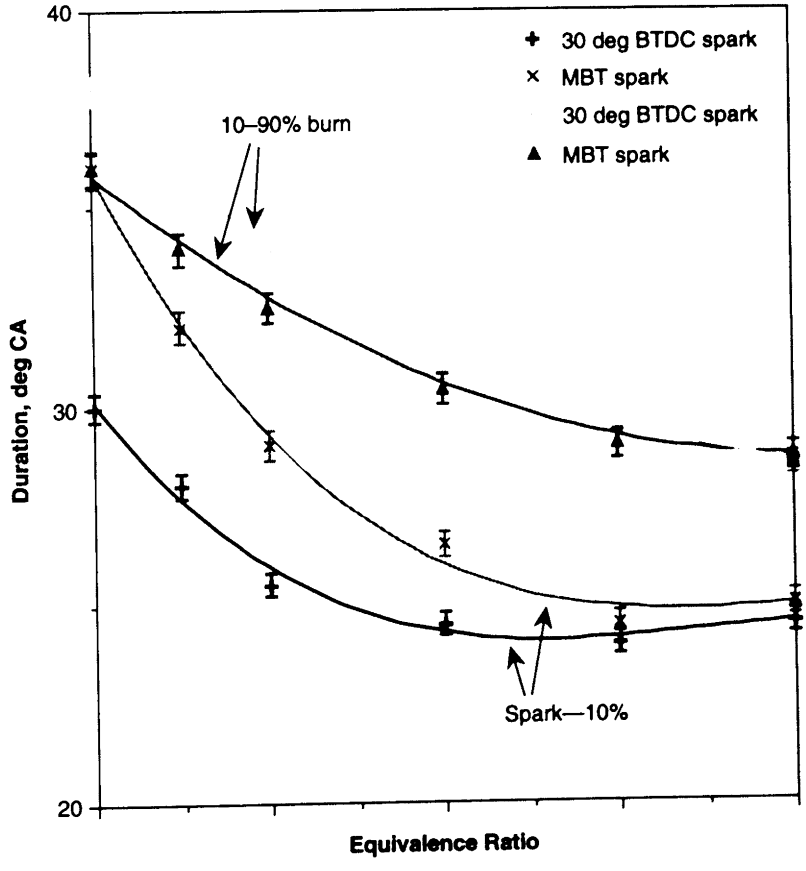

Figure 1. Flame Development and Rapid Burn Duration Dependence on Equivalence Ratio

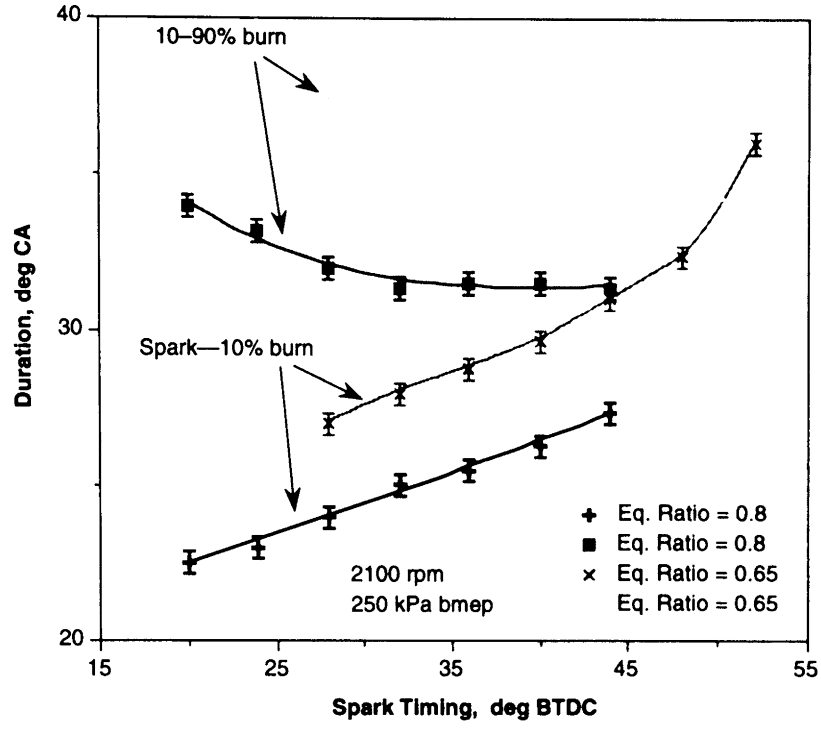

Figure 2. Flame Development and Rapid Burn Duration Change with Ignition Timing

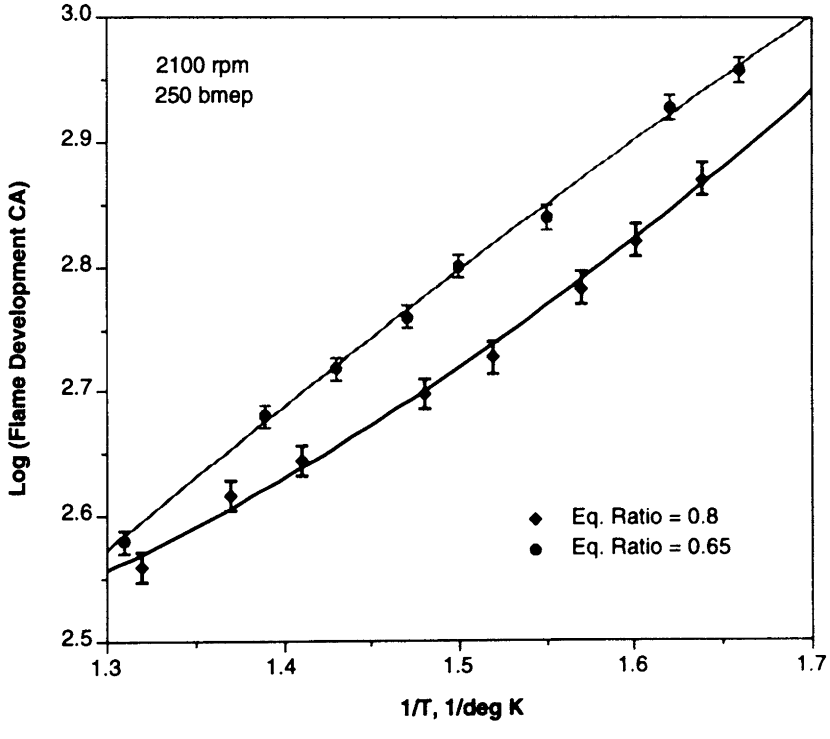

Figure 3. Relationship Between Gas Temperature and Flame Development Angle

CONCLUSIONS

The flame development angle increased as the mixture was made leaner, the major increase occurring when the equivalence ratio was reduced below 0.8. Below stoichiometric A/F ratio, rapid burn duration increased almost linearly with a reduction in equivalence ratio. The flame development angle was correlated well with mixture temperature at constant engine power levels. The correlation is useful in engine modeling and to engine designers to calibrate and control fuel management and ignition systems.

IMPACT

One graduate student was trained in experimental and modeling work on a lean-burn natural gas engine. The research work also helped the principal investigator secure NSF funding to upgrade combustion engines laboratory equipment and conduct investigations during transient operation. Some components of the study have been incorporated in a graduate course on IC engines.

Project Outline Form

Center for Engineering Education and Practice

School of Engineering
University of Michigan-Dearborn

Project Outline

Industrial Collaborator/Sponsor

Proposer:

Contact Person(s) and Collaborator(s):

Name of Company:

Address:

Phone Number:

Brief Description of Project:

Sponsorship

Can proposing company:

Provide full funding?	Yes	No
Provide partial funding with CEEP match?	Yes	No
Expect total funding from CEEP?	Yes	No

Form should be returned to:

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