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 24, 1998

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."

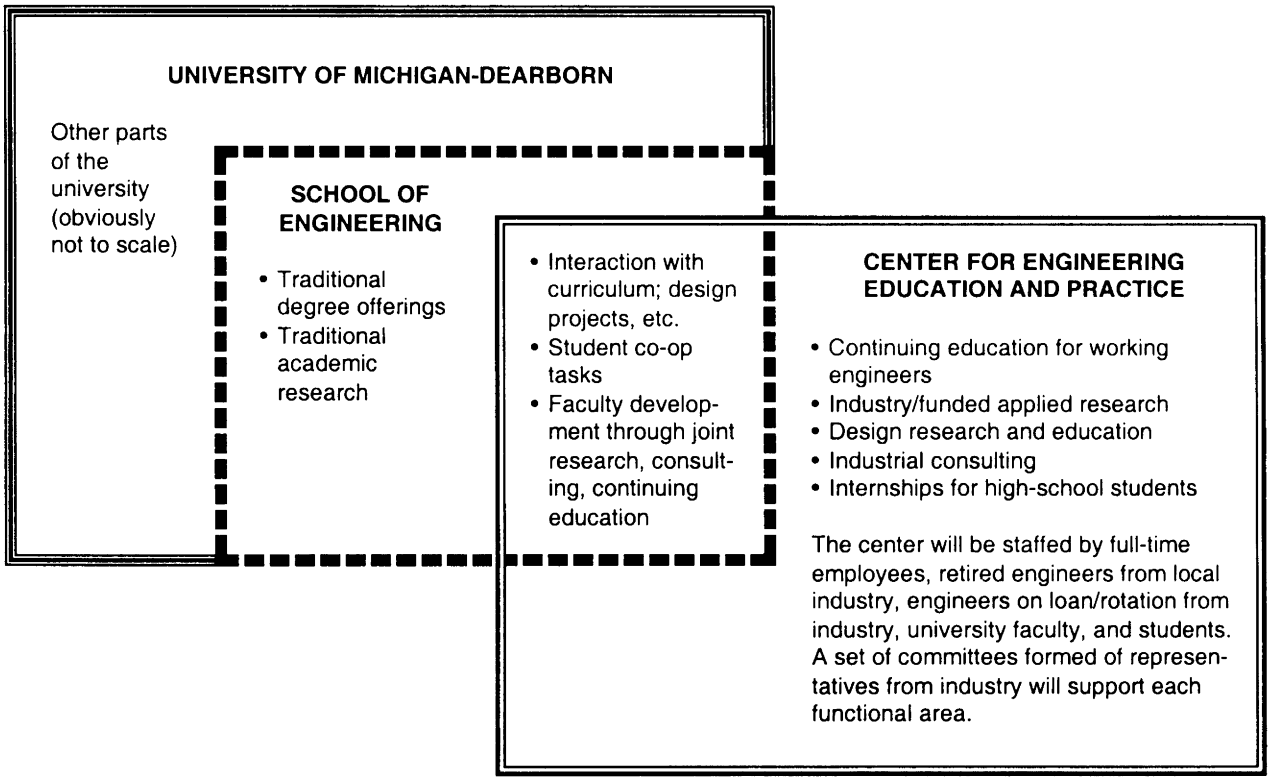
Since its inception, 70 projects have been funded, 99 individual collaborations have been supported, and over 100 course changes have taken place.

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.

Robert W. Hildebrand
Director of CEEP
College of Engineering and
Computer Science

A CLINICAL MODEL FOR ENGINEERING EDUCATION



Center for Engineering Education and Practice

School of Engineering
University of Michigan-Dearborn

Status as of June 1998
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 $3,250,000 in support has been pledged from industry.

Projects

Six funding cycles (1992-1997) 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 $3,250,000; 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 (Meritor 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
IBM-Toronto
ICAD
Jabil Circuit, Inc.
Kodak
LTV Steel Company
Medar, Inc.
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:	70
Collaborating practitioners:	99
Faculty involved:	25
Number of undergraduate students:	41
Number of graduate students/research associates:	38
Number of new courses added/planned:	19
Number of times existing courses modified:	100+

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.

Center for Engineering Education and Practice
(CEEP)

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REPORT BRIEF

Distributed Algorithms for Matrix Inversion for Heterogeneous Dynamic Networks

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Bruce S. Elenbogen
Department of Computer and Information Science

PARTNER: Brian Huf
Ford Motor Company

BACKGROUND

The mathematical basis for many CAD/CAM operations, such as heat flow, strength, and vibration analysis, involves matrix inversion. The size of the matrix is determined by the number of control points used to describe a part or set of parts to be considered. As the quality of manufacturing increases, the tolerance for error decreases, and the number of control points must increase proportionally. Parts described by a large number of control points (on the order of thousands to millions) may require the use of "supercomputers" or parallel computers to invert matrices in a reasonable amount of time. Small parts manufacturers typically do not have the computational power needed to solve these types of problems on site. However, many of these manufacturers do have networks of personal computers that have a large unused capacity.

OBJECTIVES

In this report we discuss two methods of solving the matrix inversion problem on non-dedicated networks of heterogeneous computers. The typical computers considered are 200 MHz machines with 10-Mbit ethernet connections between machines; however, the methods are applicable to any mixture of high- and low-end machines with varying storage capabilities, speeds, and operating systems that dynamically join and leave the computation.

APPROACH

We have considered three techniques for solving the matrix inversion problem: Gaussian elimination, Gauss Seidel method with over relaxation, and Pan-Reif algorithm. For all of these methods, each computer in the network is concerned with several rows of the matrix or, in the case very small computers, part of a row. The overview for all methods is that the sever will coordinate the computation by means of a Java interface. People sitting at computers with spare computation cycles can elect to contact the server and specify the capacity of the machine and the amount of time the computer can be used in the calculation. The server will distribute the initial data and coordinate data movement during the computation. Although the server will be a bottleneck for communication, this is unavoidable when the computers involved are dynamically entering and leaving the computation. The final results are sent to the server. Now let us consider data distribution of the n x n matrix to be inverted.

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,n} \\ \vdots & \vdots & & \\ & & \ddots & \\ a_{n,1} & a_{n,2} & & a_{n,n} \end{bmatrix}$$

We will divide the matrix into p groups of rows. Group i will contain m_i rows, such that $\sum_{i=1}^{p} m_i = n$. These groups will be processed independently by individual computers or by groups of computers. (In the case of some machines being too small to hold an entire row of the matrix, the rows are split among several CPUs.) The number of rows given to any computer depends on the capacity of the computer and is negotiated before any computation begins.

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,n} \\ \vdots & \vdots & & \vdots \\ & & \ddots & \\ a_{m_1,1} & a_{m_1,2} & & a_{m_1,n} \\ \hline a_{m_1+1,1} & a_{m_1+1,2} & \cdots & a_{m_1+1,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m_1+m_1,1} & a_{m_1+m_2,2} & \cdots & a_{m_1+m_2,n} \\ \hline \vdots & \vdots & \ddots & \vdots \\ \hline \vdots & \vdots & & \vdots \\ a_{n,1} & a_{n,2} & \cdots & a_{n,n} \end{bmatrix}$$

Method 1. Gaussian Elimination

Gaussian elimination finds the inverse of the matrix A so the that the problem Ax = b can be solved for a set of b's without recomputing A^{-1}. Each set of rows is then reduced to an upper triangular matrix using standard Gaussian elimination. The top rows from each computer are sent to the first computer; the second set of rows from each are sent to the second computer. Another Gaussian elimination is done and the process is repeated, with the exception that finished rows are retired from computation.

Method 2. SOR

The SOR method solves a single problem of the form Ax = b, when the matrix A is positive definite. This restriction is true for many situations. A guess is made for the solution vector x, and then successively better approximations are made. These approximations are made for each set of rows by multiplying the entire approximation by the old approximation and adding a vector.

$$u^{(i+1)} = \left(I - D(A)^{-1} A\right) u^{(i)} + D(A)^{-1} b$$

where D(A) is the diagonal element of A.

Method 3. Pan-Reif

This algorithm will also compute the inverse matrix as in Gaussian elimination but converges much more slowly than the SOR method. In this method, an initial guess is made for the inverse of the form

$$B = \frac{A^H}{\left(\|A\|_1 \|A\|_\infty\right)}$$

Successively better approximations to this inverse are made by computing the power series

$$\sum_{i=0}^{2^{k+1}-1} R^i \text{ where } R = I - BA$$

RESULTS

Gaussian elimination on a 1000 x 1000 matrix displayed a balance of communication and computation. The computation time to invert an n x n matrix is inversely proportional to n/(average m_i). The computation is dominated, however, by the most powerful CPU on the network (if it is placed first). The communication time is also inversely proportional to n/(average m_i); however, the communication time is very dependent on the congestion in the network. Although communications naturally separate, a congested ethernet presents severe limitations.

The SOR method had the least computation time but had double the storage requirements of Gaussian elimination. The communications cost was similar. Again, the method showed a linear speed-up in the number of processors of approximately equal size.

The Pan-Reif method had the highest communication cost, making this method the slowest of the three. The Pan-Rief had a lower numerical complexity, making it a viable choice, especially on a switched or broadband network.

CONCLUSIONS

All three methods are applicable for certain situations. The size of the matrix and the speed and type of network are all highly important in determining the best algorithm for a given situation. For a typical network, however, positive-definite-matrices SOR is the clear choice. For well-conditioned matrices, Gaussian elimination works well.

The choice when nothing is known about the matrix is Pan-Reif. Although this algorithm can be slower than Gaussian elimination on some networks, its numerical stability is higher, and it can be run to a required degree of accuracy.

IMPACT

This work was developed as part of the CIS 490 course on parallel and distributed computing. Students found that algorithms used on parallel computers do not always make the best choice for working on a distributed network of computers. This work was used to point out the differences between theory and practice and to give insight into how to optimize distributed programs. This work can be used to make viable products to be used in local industry. The viability of using networks as parallel computers will only increase as gigabit ethernet and ATM computing become more commonplace.

REPORT BRIEF

Integrating Imaging Technology in Organizations

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR:	Roberto R. Kampfner Department of Computer and Information Science
PARTNERS:	Conrad Foster and Charles Oesterle CEO Image Systems, Inc.
ASSISTANT:	Loretta Thiry Department of Computer and Information Science

BACKGROUND

CEO Image Systems is an organization that supplies imaging technology for document processing. Dr. Roberto R. Kampfner of the computer and information science (CIS) department, in a joint venture with Mr. Conrad Foster and Mr. Charles Oesterle of CEO Image Systems, is conducting research on the use of imaging technology in organizations. Ms. Loretta Thiry of the CIS department is assisting in the implementation of a pilot project in the CIS office.

OBJECTIVE

The objective of this project is to illustrate the effective use of document imaging technology in an organizational context. An important goal of the research is to develop ways of using the imaging technology provided by CEO Image Systems as a means of enhancing the function support capabilities of information systems.

APPROACH

The approach uses the function-support framework for the development of information systems. This framework is used in conjunction with the document imaging techniques developed by CEO Image Systems. The presentation shows how key information requirements for the support of organizational functions in a business, educational, or industrial environment, can be met with the appropriate kind of information technology. In particular, a pilot project being developed for the CIS department office applies the document imaging technology developed by CEO Image Systems to the solution of document storing and processing in the department.

The goals of the research include the use of the function-support framework as a basis for the development of principles and methods for the use of document imaging technology in organizations (see Figure 1). 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.

FUNCTION-SUPPORT AS AN INFORMATION PROCESSING PARADIGM

One basic idea is that, to be effective, information processing 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. To integrate document imaging into the dynamics of organizational function, the way in which document imaging interacts with other systems must be compatible with the dynamics of the functions using the imaging technology.

RESULTS

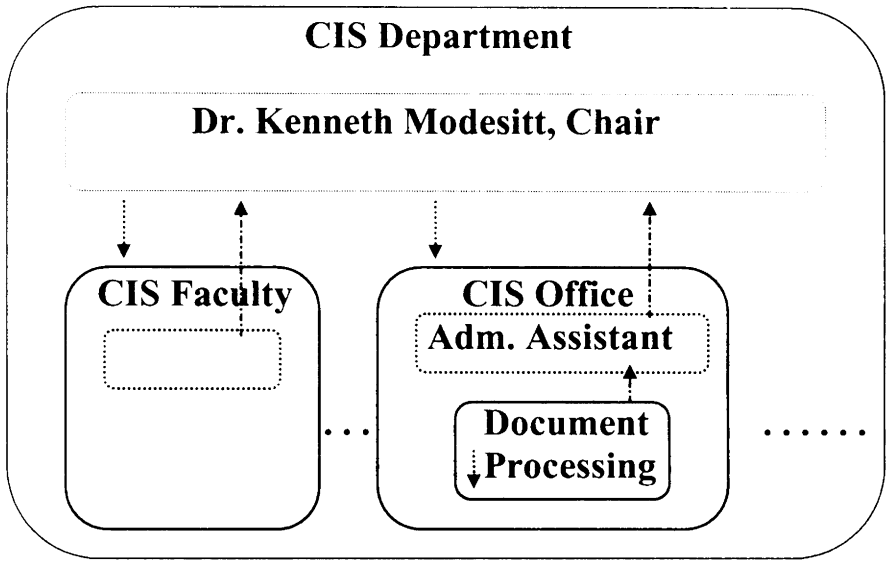
Expected results include the integration of image processing technology into the information system supporting the CIS department office, and to incorporate the implementation principles developed for this technology into the methodology of information systems analysis and design.

CONCLUSIONS

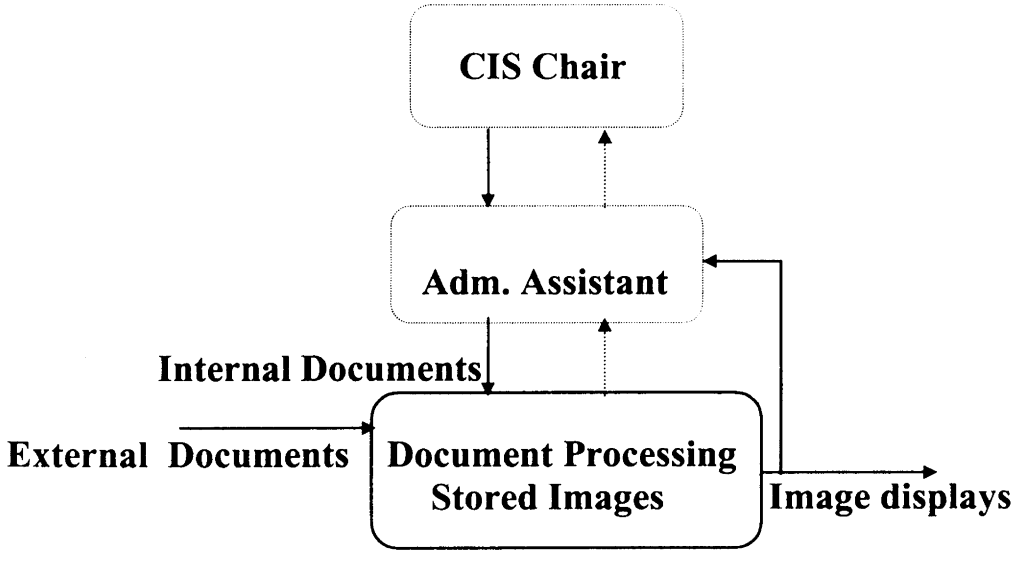
The pilot project will help provide specific solutions to the integration of image processing technology in an academic environment. It will certainly shed light on the solution to the general problem of integrating imaging technology in organizations. It will also help to tackle the challenge of integrating 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 computer and information science department of the University of Michigan-Dearborn. The idea is to provide a continuing model for research and collaboration on conceptual, technical, and methodological issues.



a)



b)

Figure 1. Part a) shows part of the structure of the CIS department. Part b) shows information flows relevant to document processing.

REPORT BRIEF

Design of Multicast ATM Packet Switch

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHORS: Rajgopal Kannan and Sibabrata Ray
Department of Computer and Information Science

BACKGROUND

The asynchronous transfer mode (ATM) technique is widely accepted as a basis for transporting and switching broadband user traffic with bit rates ranging from Mb/s to Gb/s, where user information is packetized and carried in fixed-length ATM cells.

ATM switching technologies may be viewed from two distinct perspectives. From the end-user's point of view, the performance of the switch should meet the following requirements: reliable end-to-end transport of packets in sequence; high bandwidth network connections, typically 100 Mbps or more per workstation; consistent bit-rate service with only small network delays, which is essential for video traffic; and scalable user bandwidth allocation based on the application's quality of service (QoS) requirement, which facilitates new classes of applications such as multimedia. From the architectural point of view, the switch should be designed to meet the required QoS guarantees by reliably switching packets at low packet loss probabilities and with a minimum of switching delays. In addition to providing point-to-point connections among user pairs, the switch architecture must also support multicast and broadcast capabilities.

Many multicast switching architectures have been designed to implement ATM switching techniques. However, none of them are completely satisfactory from the point of view of system size, scalability, latency, and hardware costs. Thus there exists a need to design a better multicast ATM switch free from most of the flaws of its contemporaries.

OBJECTIVE

Design and implement a multicast ATM switch that is scalable to large sizes, and has superior latency and hardware complexity compared to existing switches.

APPROACH

Recently, many ATM switch architectures have been designed for point-to-point (unicast) and/or point-to-multipoint (multicast) switching. Many commercial ATM switches are single stage switches based on shared memory such as the Foreswitch. These switches require enormous internal speedup, which in turn limits their size. For that reason, our primary focus is on interconnection network-based ATM switch architectures.

Figure 1 shows a block diagram of MSXmin, the proposed N x N multicast ATM switch. The network consists of n stages of multicast-sort-expander (MSX) modules, labeled from 1 through n from right to left, where $n = \log_2 N$. Stage i, $1 \leq i \leq n$, consists of 2^{n-i} MSX modules. The notation MSX (i, j) refers to the j^{th} MSX module in stage i, $0 \leq j \leq 2^i - 1$. On considering MSX modules as single nodes, the interconnection pattern between modules is that of a complete binary tree with parent module MSX(i,j) linked to child modules MSX$(i - 1,2j)$ and MSX$(i - 1,2j + 1)$ and MSX$(i - 1,2j + 1)$ via an unshuffle

operation at the outputs of MSX(i,j). An MSX module in stage i has I_i input links from its parent module and O_i output links to each child module in the next stage.

Figure 2 illustrates the schematic of an MSX module in the i^{th} stage. Each MSX module consists of three components: a pair of concatenated I_i x I_i reverse banyan networks (RBNs), followed by a routing module consisting of a single column of O_i dual-bit controlled 2 x 2 switching elements (SEs). The inputs to the first RBN are derived from the parent MSX module in the previous stage (stage $i+1$). The I_i output lines from the second RBN are connected in a wraparound pattern to the single column of O_i switching elements in the routing module. A perfect unshuffle is performed at the outputs of the routing module such that output lines from the upper (lower) ports of the SEs are directed to the upper (lower) child MSX modules in the next stage (stage $i-1$), as illustrated in the figure.

Our design methodology for a modular, scalable MSXmin switch with a given packet loss rate is as follows; i.e., let L be the maximum overall packet loss rate for which the switch needs to be designed. We assume that the design parameter L has been calculated based on standard operating conditions such as as the transmission bit rate and bit error rates within the switch. I_i and O_i values for MSX modules in each stage are calculated such that the expected packet loss at any MSX module at an effective input load of 100%, is no more than L. Note that the normal operating parameters of the switch call for an effective load around 80% or 90%, since the packet loss in the buffers increases rapidly beyond this point.

RESULTS

It can be shown rigorously that the expansion ratio of Oi / Ii at each stage is a decreasing function for any value of L. It can thus be shown that the overall hardware complexity of the switch is O(N log2 N) and its internal latency is O(log2 N). This is superior to contemporary ATM switches in the literature. Furthermore, the switch is modular and scalable to large sizes. No special techniques are required for maintaining cell sequencing. The switch is comparable to other multicast switches in terms of the header overhead and translation table complexity.

IMPACT

The demand for high-speed networks is ever increasing (multimedia applications, Internet 2, etc.) The technology developed within this project delivers a high-performance high-speed network at a much lower cost, while also allowing for any future expansion in network size.

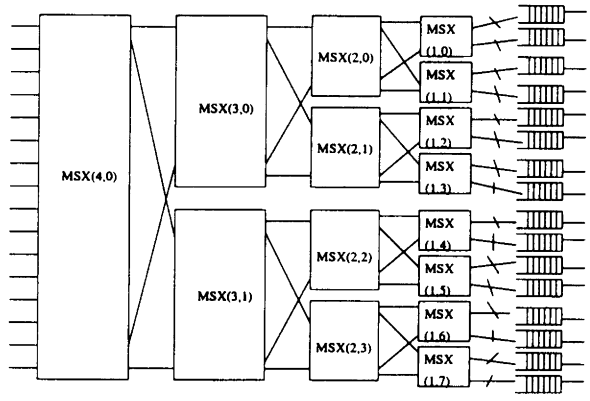


Figure 1: Schematic of $N \times N$ MSXmin for $N = 16$.

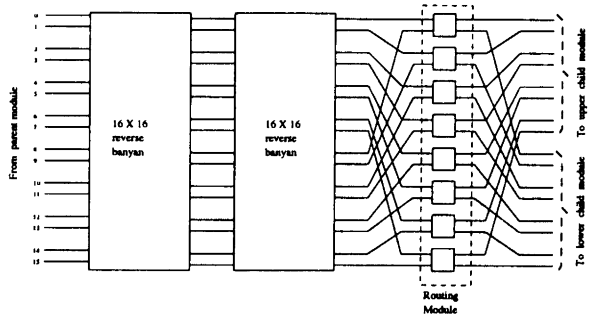


Figure 2: An MSX module in stage i; (MSX(1,0) for a 16×16 MSXmin).

REPORT BRIEF

Back to the Future: PLATO® on the Internet at UM-D in 1998 Starting from the University of Illinois in 1963

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

Over 80% of our undergraduate students work at least 20 hours/week and 98% of our graduate students work full-time. All of them commute, with every ten-minute daily round-trip commute to campus requiring one workweek on the road annually. Translate this to a fully-loaded engineer (i.e., salary, fringe benefits, and overhead) and the cost easily exceeds $2,000 annually. Multiply this by the appropriate factor in case you have more than a five-minute drive from work or home to the University of Michigan-Dearborn (UM-D). This fact is a major reason for the increasing role of information technology (IT) in the College of Engineering and Computer Science as it enters a new phase. A significant point in the history of IT occurred when PLATO first appeared on the engineering campus of the University of Illinois in the early 1960s (when one of the authors first encountered the system). The use of IT is a major paradigm shift from a mode emphasizing "teaching by professors" to one of "learning by students." See Figure 1 for why such a shift is desirable—learning by doing is far superior to instruction being "delivered" solely by lecture. This is part of a more holistic effort for building a distributed intelligent community involving UM-D—see Figure 2.

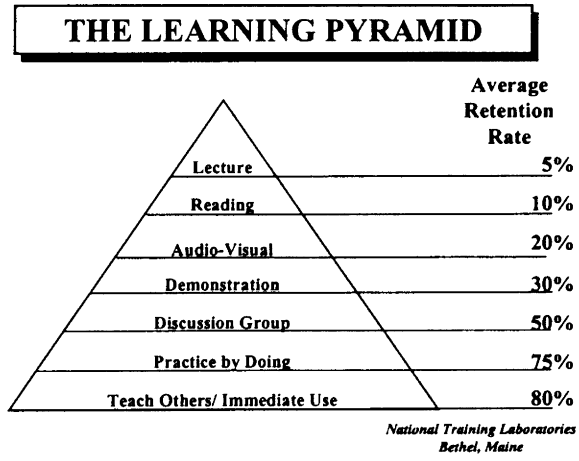

Figure 1. The learning pyramid [National Training Labs, 1994]

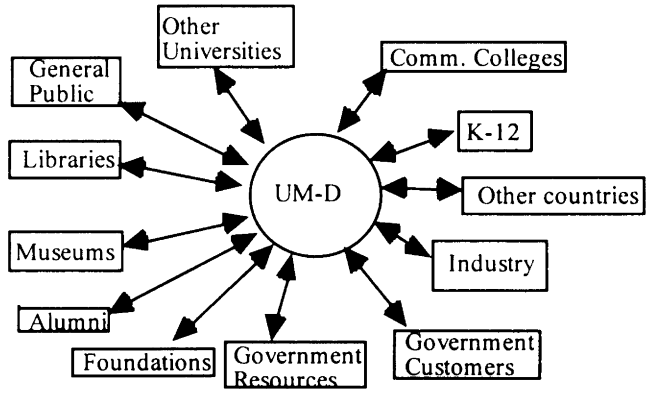

Figure 2. The distributed intelligent community of UM-Dearborn [Modesitt, 1995]

OBJECTIVES

Supplement current practices related to learning with a more accessible delivery mechanism used by learners (students and faculty):

- at the university
- in the work place
- in community colleges
- while traveling on business
- at home

APPROACH

Provide asynchronous learning opportunities via:

- Proven integrated and comprehensive educational software (courseware), using PLATO delivered over the Internet
- Desktop video conferencing via Microsoft® NetMeeting, CUSeeMe, and Connectix Quick-Cam®

RESULTS

Several courses have used PLATO and desktop video conferencing during the past three years. Usage included the study and implementation of such systems, as well as the use thereof to provide learning asynchronously. Remote dial-in from student homes to the CIS server permits several students to view the same screens simultaneously, thus permitting collaboration on software development concerns. PLATO is being used in a number of courses across campus. The integration of desktop video conferencing (DVC) and PLATO is planned for the fall of 1998 in several courses, including software engineering and capstone design. A pool of Quick-Cams is available for checkout by students and faculty for access to campus computing resources from homes and business offices. A CUSeeMe reflector (server) has been set up for multi-point desktop video conferencing.

CONCLUSIONS

This pilot effort is worth expanding to additional courses and markets, on an as-need basis. Some markets for the courseware/desk-top video conferencing will include those of continuing engineering education. Other markets will be for additional courses on-campus which use the highly interactive and graphical nature of the PLATO courseware.

IMPACT

A high-quality educational experience will be more accessible to individuals and organizations on demand. Students will spend more time learning instead of commuting.

Industry and their employees will save valuable time and money. The same will be true for students at the university and participating community colleges.

ACKNOWL-EDGMENT

Dean Sengupta of the College of Engineering and Computer Science, Provost Simpson of the University of Michigan-Dearborn (Chancellor's Technology Grants and PLATO Pilot Test), and TRO Learning Corporation are acknowledged for their support of this effort.

Department of Electrical and Computer Engineering

REPORT BRIEF

Computer Assisted Treatment for Motor Speech Disorders

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Electrical and Computer Engineering

PARTNER: Dr. Richard Merson
William Beaumont Hospital

BACKGROUND

The subject of this project is computer-assisted treatment for individuals with motor speech and sensory disorders. The focus groups include individuals with stuttering and speech impairment as a result of Parkinson's disease. An integrated software-based system was developed to serve as a speech fluency shaping aid for speech-language pathologists treating individuals with motor speech disorders. A version of this speech fluency aid for stuttering patients, developed by the authors of this proposal, is undergoing clinical evaluation trials at William Beaumont Hospital's (Royal Oak, MI) Stuttering Center in the speech-language pathology department. This software has demonstrated great potential to aid stuttering patients. The new software package, Prosidy v1.0 (see Figure 2), has just begun clinical evaluation trials at William Beaumont Hospital.

OBJECTIVE

This project proposes to continue the development of a real-time fluency therapy aid that is affordable to speech pathology clinicians and individuals with speech fluency disorders. Such speech disorders include stuttering and speech impairment due to hearing impairment and diseases like Parkinson's and Multiple Sclerosis.

APPROACH

The speech fluency computer-based system is built around a personal computer (PC) with a Windows 95 operating system and a sound card. The speech processing is done in real-time. The software is written to be user-friendly and intuitive. It records the progress of the clients such that the results can be available during doctor visits. The performance of the system is continually being fine-tuned through the comments and feedback obtained from clients.

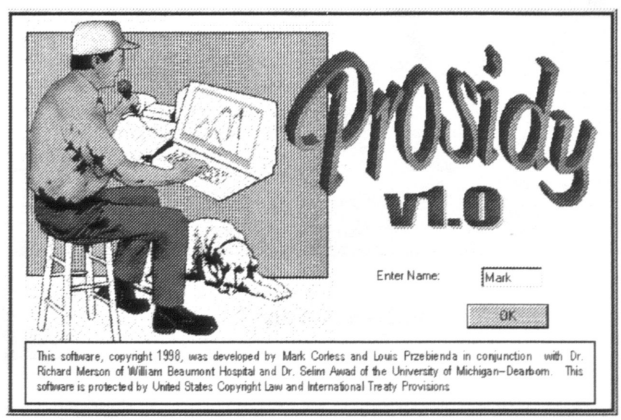

Figure 1: Parkinson therapy aid startup screen

Over the last year, an improved version of the software for stuttering clients has been developed and is being tested at William Beaumont Hospital. Software installation has been simplified for patients who lack computer experience. Scoring has been improved, and multimedia motivational elements have been added. The following tasks are currently being investigated:

1. Further development of the animation engine that changes animations to follow client improvement
2. Creation of a skeleton of the analysis code so that both the stuttering and Parkinson versions of the software can access the same functions
3. Further improvement of scoring and comparison analysis
4. Development of a script to import database information into Excel to ease clinical evaluation
5. Modification of software for other patient populations, such as Multiple Sclerosis or hearing impaired

A database file is created for each client. This file records the patient's practice times, which phrases were attempted, and the scores for the analysis. The software scores start time, end time, duration, onset, loudness, and shape for the stuttering version. The Parkinson version only scores the start time, end time, duration, and loudness.

A new evaluation feature has been added to allow comparison and analysis of computer versus clinician scoring values. This feature allows the clinician to choose which patient attempts to save information for. Attempt information includes the name of the client, the WAV files of the clinician and client utterances, the scores generated by the computer, and the scoring information provided by the clinician. The evaluation dialog box is shown in Figure 2. The clinician can replay both the goal and client phrases, see the average magnitude plots of each, and then score the data as appropriate. An option is available to view the computer's score for each attribute. All of the previous information is recorded to a file. This file allows the developers of the software to record and plot this information. Analysis of this information will show which portions of the scoring algorithms need improvement.

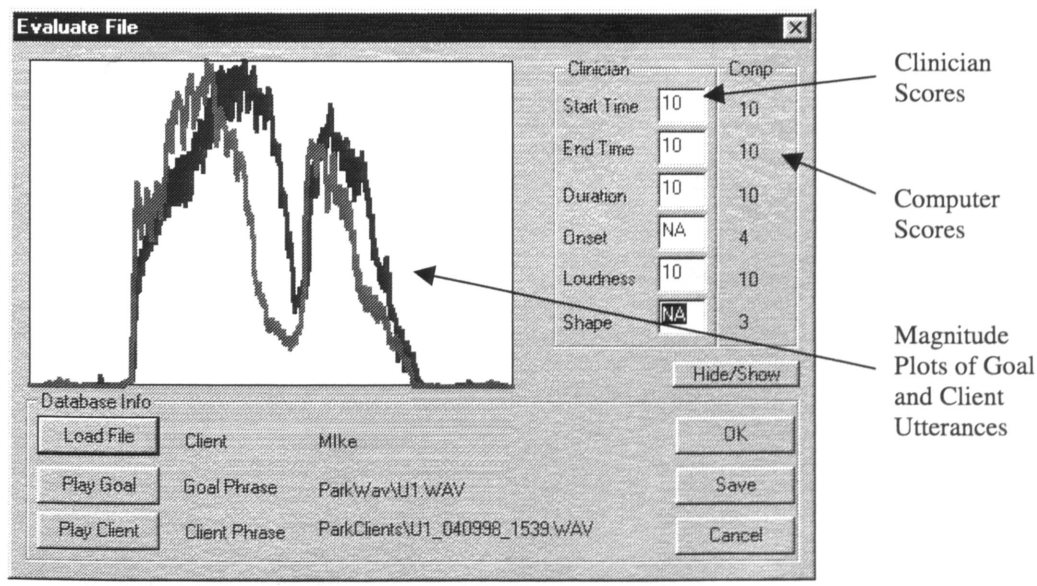

Figure 2. Evaluation dialog box

RESULTS

Prototype software for the stuttering and Parkinson speech fluency treatment aids is currently being tested clinically at Beaumont Hospital. Approximately 15 adults and children who stutter have used this software with demonstrable success in speech fluency modification. Testing of Parkinson patients began in April of 1998. A new formula for scoring the general shape of the amplitude wave has been developed and integrated into the speech fluency software.

Currently, the stuttering version of the software uses an animal animation theme. Frog sounds and pictures have been added to make the application more fun for children. An animation engine focussing on racecars is also being developed to further motivate students to use the product. The Parkinson version of the software is based on 1940s-style graphics.

Mr. Mark Corless has rewritten much of the software, making it more modular. He has also upgraded the development environment to Microsoft Visual C++ 5.0. This upgrade tremendously decreases debug time. Software installation has been attempted at a patient's home, but the client's computer system had operating system problems and had to be repaired before installation could be reattempted. The client recently notified the college of the repair and a new installation date has been scheduled.

IMPACT

This project has produced a real-time speech fluency system that is affordable to speech fluency disorder clients. This system will provide a means for them to improve their speech fluency at home. As a result, we hope that it will decrease the medical costs associated with this type of therapy.

Graduate and undergraduate students have participated in this project. M. Corless, a graduate student, is currently working on the project as part of his master's thesis. He intends to implement the improvements discussed in the objective section. Another graduate student, Bret Bentzinger, has begun assisting in the Visual C++ code development and testing.

Topics from this project (e.g., the application of digital speech processing applied toward speech therapy) have been included in ECE 584 (Digital Speech Processing), ECE 480 (Digital Signal Processing), ECE 491 and ECE 591 (undergraduate and graduate directed research courses).

REPORT BRIEF

A Low-Cost In-Process Gauging System

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Research Assistants

BACKGROUND

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

OBJECTIVE

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, measurements of interest are the two diameters of the crimp and the bell length. In order to minimize costs, it was also desired to use a single computer for multiple stations.

APPROACH

In order to gauge both types of parts, a video camera is used to acquire a back-illuminated image or silhouette of the part. The video image is then digitized with a frame grabber and stored in computer memory. The digitized image is processed so that key features in the image can 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 industrial personal computer. In order to minimize hardware costs, a standard 50mm C-mount camera lens and extension tube was used with the video camera. For image acquisition, a low-cost PCI-bus frame grabber-card was selected. 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 at very low cost. A camera multiplexer is used to access data from each camera for different measurements.

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 background 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. Measurements of interest for the break hose crimp are illustrated in Fig. 3—the two crimp diameters and the bell length.

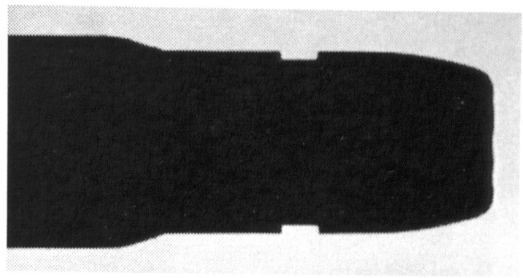

Figure 1. Back-illuminated part with groove

In order to provide these measurements, 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.

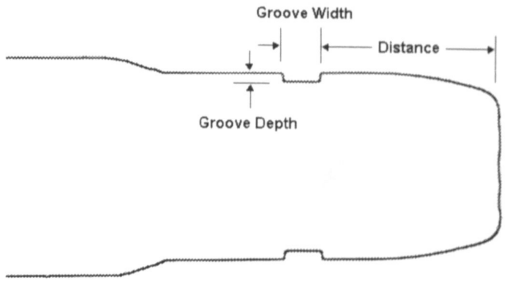

Figure 2. Groove dimensions to be gauged

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. 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.

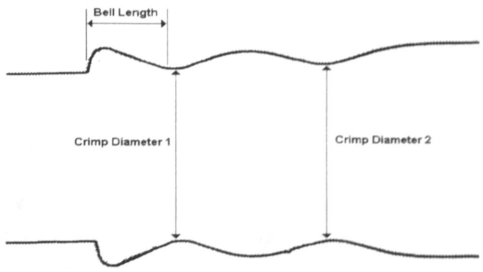

Figure 3. Crimp measurements

A graphical user interface (GUI) 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 4.

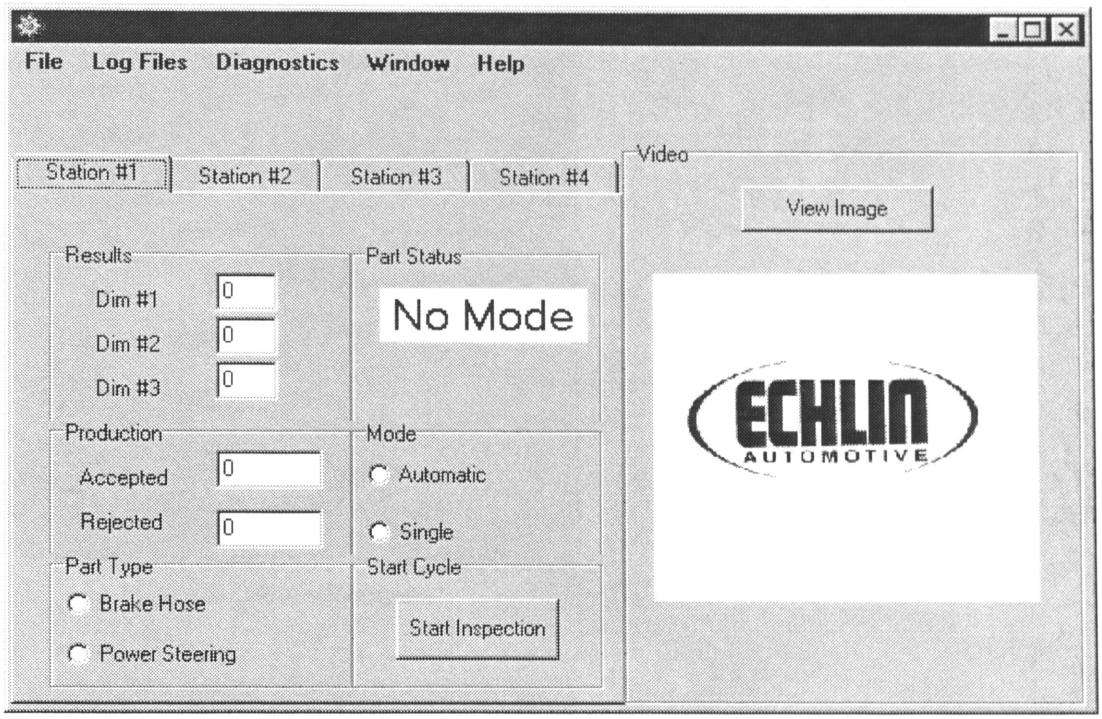

Figure 4. Vision system graphics user interface

Enhancing the original gauging system so that it would handle four individual stations was a significant challenge. Providing adjustments for each station in a user-friendly manner was not overly difficult, but did require a careful design effort. Performing the analysis for each image in real time was significantly more difficult. After a careful examination of different programming approaches, threaded code was employed. This approach would tend to minimize delays when more than one station has a part ready to be gauged and not impose overly severe demands on system resources such as memory.

The GUI contains four different forms for gauging, calibration, tolerance adjustment, and process information. Implementation of the gauging window to display results and provide the user access to the various features of the application for each station was obtained with the use of a Tab Sheet control. The Tab Sheet control contains a tab for each station. When the user selects a tab, the features for the selected station are displayed. Furthermore, each station sheet or tab of the Tab Sheet control appears exactly the same to the user. As illustrated below (see Figures 5 and 6), calibrating the system and establishing tolerance limits can be accomplished in a very straightforward manner.

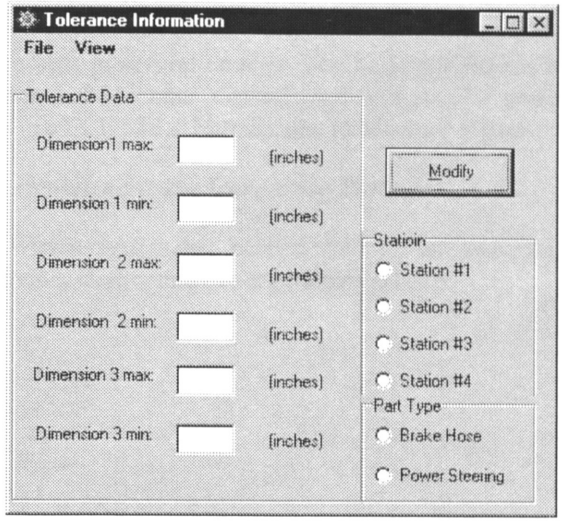

Figure 5. Calibration menu

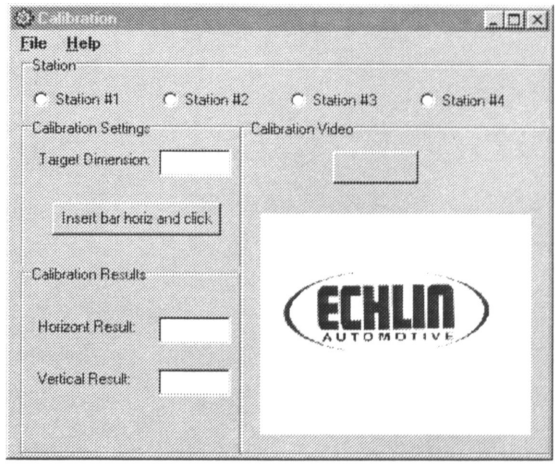

Figure 6. Tolerance menu

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, and measurements for a given station are completed in under two seconds.

IMPACT

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

♦ *Excellent Experience for Participating Students*

The students acquired a variety of new skills including knowledge of 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 ECE 588, "Applied Machine Vision," and will also be presented in the new undergraduate vision course ECE 588, "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

Fuzzy Learning In Engineering Diagnosis

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
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Research Assistant

BACKGROUND

Fault diagnosis is a classic engineering problem. Particularly, automotive fault diagnosis has the following difficulties:

- Knowledge concerning most vehicle diagnostic problems is incomplete and vague due to the complexity of modern vehicles.
- Different vehicle models have different engineering features, e.g., the Ford Thunderbird is very different from the Lincoln Town Car. Furthermore, the 1996 Thunderbird may be different from the 1997 Thunderbird.
- Often the data available for learning is not complete; it is important for fuzzy systems to combine human expert knowledge with the knowledge learned from data samples.
- When the vehicle model changes, we have very little data available from which to build the fuzzy knowledge base. It is important for the system to have the ability to accumulate learning.
- Data samples of "good" vehicles and "bad" vehicles (those vehicles with the problem to be diagnosed) are often unbalanced. The data acquired at an assembly plant generally contains 99% "good" vehicles and 1% "bad" vehicles.

OBJECTIVES

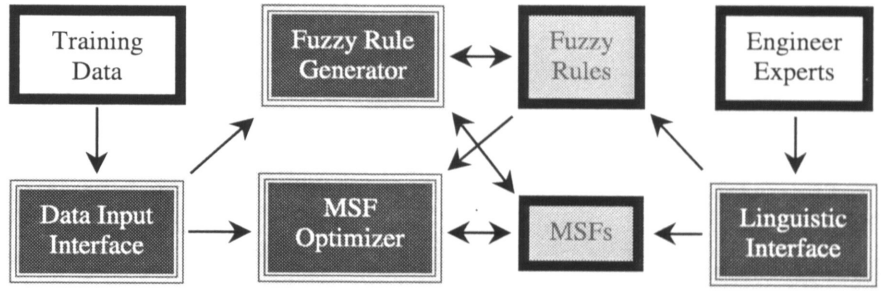
(1) The problems outlined above will be solved using fuzzy system techniques; (2) an intelligent fuzzy diagnostic system will be created for end-of-line vehicle tests in assembly plants; and (3) an intelligent fuzzy system will be created that can automatically generate the required knowledge base, including fuzzy rules.

APPROACH

We applied fuzzy logic and machine learning techniques to solve this problem. A fuzzy intelligent system for electronic engine controller (EEC) vacuum leak diagnosis was developed. The system has two major components:

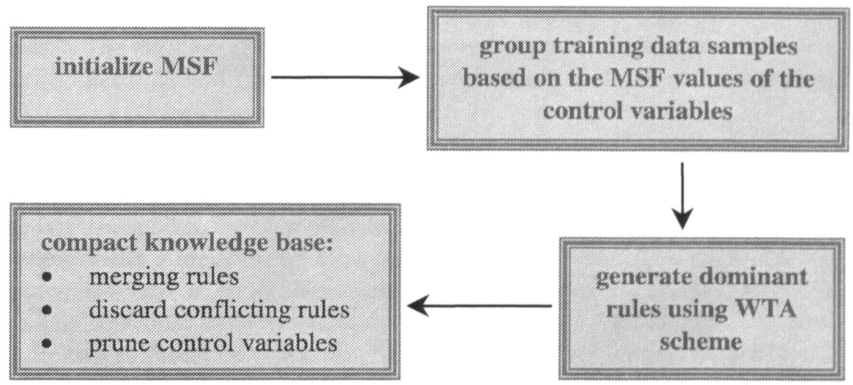
1. Learning engineering diagnostic knowledge
   - Automatic fuzzy rule generation
   - Automatic fuzzy membership function optimization

2. Engineering fault diagnosis
   - Learning diagnosis knowledge

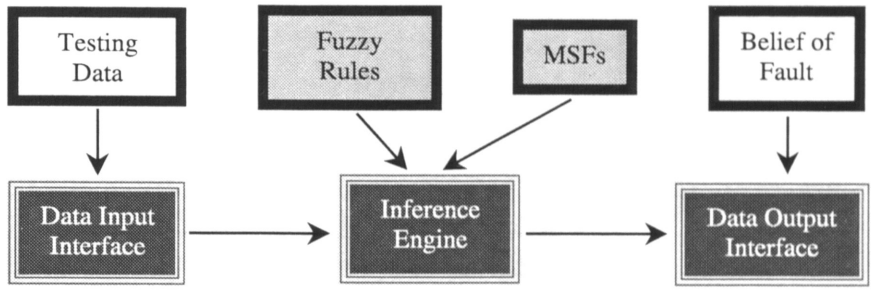


Note: Here MSF stands for *Fuzzy Membership Function*.

   - Fuzzy rule generation
     - Fuzzy rules generated from engineering heuristic knowledge
       - → Engineers generate fuzzy rules through an interactive linguistic interface.
       - → Engineers modify the fuzzy rules generated by the system.
     - Automatic fuzzy rule generation from training data



   - Membership function optimization
     - MSFs are represented by triangular functions.
     - MSF optimization is to find the best locations and overlap of the triangular functions.
     - Optimization methods investigated:
       - → Gradient descent method
       - → Stochastic annealing method
     - Fuzzy engineering diagnosis



RESULTS

An algorithm has been developed for automatic fuzzy rule generation.

- An intelligent fuzzy system has been developed and implemented for diagnosing EEC vacuum leak. The system is capable of learning the characteristics of different vehicle models and performing robust testing. The system is in the process of being implemented into Ford Motor Company's diagnostic systems.
- The fuzzy diagnostic system was tested on data sets of over 20,000 samples; the accuracy of the system was above 96%. We tested the system on two different types of vehicle models:
  - Ford Thunderbird (1995 and 1996 models)
  - Ford Lincoln Town Car (1996, 1997, and 1998 models)
- 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 $93,450.00. Ford Motor Company has also provided funding in the amount of $40,000.00 for a period of two years.

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 integrated into a fuzzy diagnostic system that detects vacuum leaks in the electronic engine controller in automobiles. The fuzzy vacuum leak diagnostic system has been tested on two different vehicles, the Thunderbird and the Lincoln Town Car. The testing results show that the system is effective, fast, and compact, suitable for running on a PC platform.

IMPACT

Educational impact:

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

Industrial impact:

- The system developed from this project is being transferred to a Ford diagnostic program to be used in Ford assembly plants.

REPORT BRIEF

Image Content Based Retrieval in Multimedia Databases

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
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BACKGROUND

Multimedia databases are a convenient media for describing and storing image, text, voice, spatial, temporal, spectral, and physical components of information. Many large multimedia databases are being created and used in applications such as astronomy image storage and geographical information systems. However, because of the large volume of data in the databases, it's difficult to find useful information. Therefore, efficient and automatic algorithms are required for retrieving information from large databases. The focus of this project is on digital image retrieval, the most difficult task in multimedia database retrieval.

At present the most common technique for integrating images in a database is to record them together with textual descriptions. However, textual descriptions are inadequate because the complexity of the information imbedded cannot be synthesized in a few key words. There is a growing demand for retrieval systems using pictorial information for both commercial and cultural applications.

OBJECTIVES

There are two ways a retrieval system can assist users in the retrieval of information:

- Browsing: users can select some attributes provided by the system such as color, position, texture type, or name, and the system will find the corresponding image from databases.
- Query: users can select an image as "query image." The system will find images similar to the "query image."

We will implement both approaches in our system. Color and shape information is selected to assist the content based image retrieval.

APPROACH

Color feature:

We selected the dominant color, which occupies the largest percentage of the image, as a color attribute. More attributes will be added in a future version of the system.

To make the retrieval efficient, we selected twelve normal colors and three special colors as basic colors. The twelve normal colors are YELLOW, ORANGE, RED, HOTPINK, MAGENTA, VIOLET, BLUE, SKYBLUE, CYAN, SPRINGGREEN, GREEN, and GREENYELLOW. The three special colors are WHITE, BLACK, and GREY.

All of the basic colors are defined in CIELUV color space instead of RGB (red, green, blue) space. The most popular color space is RGB. Every color is described with three components—red, green, and blue. RGB is very convenient for computer display. However, RGB's shortcoming is that it is not perceptually uniform. That is because the real color differences are much different from those that can be sensed by humans.

This problem can be solved in CIELUV color space, which closely approximates the color differences sensed by humans. CIELUV is produced by plotting the quantities L^*, u^*, and v^*, which are obtained by a non-linear transformation of the tistimulus values XYZ in a three-dimensional Cartesian space. The difference between two color points is measured with the Euclidean distance of (L^*, u^*, v^*). The variables u^* and v^* make it possible to evaluate correlations of hue (h^*) and chroma (C^*):

$$h^*_{uv} = arctg(u^* / v^*) \quad \text{and} \quad C^*_{uv} = \sqrt{u^{*2} + v^{*2}}$$

Fifteen "center" or "representative" colors are selected as basic colors. All of the other colors belong to the closest "center" color according to the distance between its hue h^* and hues of the "center" colors when the color's lightness L^* is moderate. Otherwise, further decisions should be made to determine if the color belongs to WHITE, BLACK, or GREY.

After having defined the basic colors, we can easily get the global color histogram of the image. This information is used in the "browsing" retrieval mode. For the "query" mode, the image is divided into four subregions of equal size, and four local color histograms of fifteen basic colors are extracted to get a more accurate similarity measurement.

Shape Feature:

To obtain shape features, the image is first divided into three images in which every pixel value is the red, green, or blue component of the original image. The Sobel operator is applied on the three images to find the gradient of each pixel, namely G_r, G_g, and G_b. And if G=max (G_r, G_g, G_b) is larger than some threshold, the pixel is regarded as the "edge pixel." The edge pixels are divided into eight classes according to the direction of their gradients.

The whole image is divided into four subregions. In each subregion, the number of eight different kinds of edge pixels is counted and an 8-bin normalized edge pixel histogram can be calculated. The element of each histogram is actually the percentage of different edge pixels of each subregion. During retrieval, the sum of the Euclidean distance between four histograms is the measurement of shape distance between two different images.

RESULTS

A content based image retrieval system was implemented under a UNIX operating system. The system is composed of the following parts (Figure 1):

- There are three image databases in the system. One is the Astronomy Image database collected by the University of Michigan, Ann Arbor. The other two databases, car and human face databases, were collected by the authors.

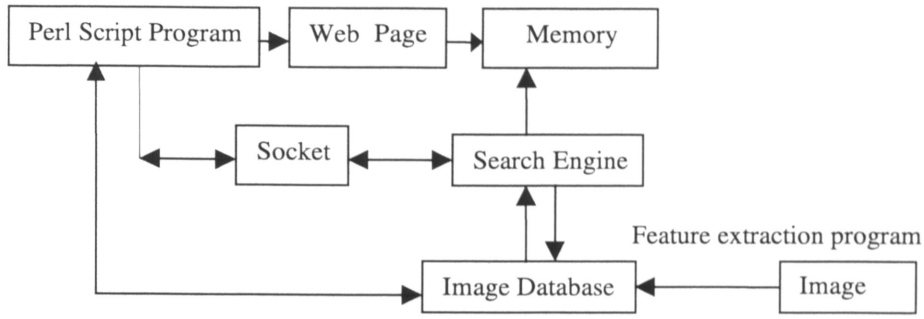
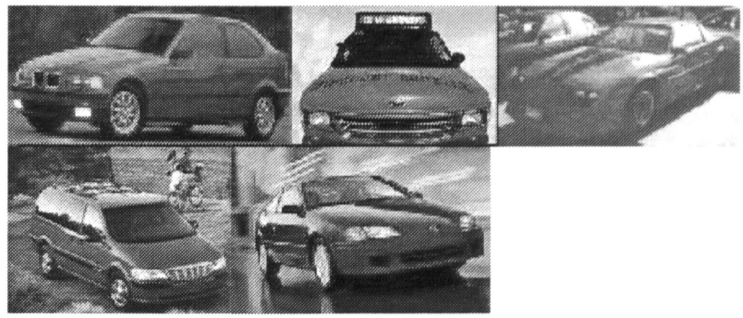


Figure 1. Image retrieval system

- The role of the feature extraction program is to extract color and shape features from images. This work can be done in advance and offline.
- The search engine waits for any query request from users. After it gets such a request, it will search the whole image database and return the query result to "Perl Script program," which can construct a web page so that users can view the retrieved images through Netscape® or Explorer®.
- On the web, users can select either the browsing or query approach for retrieval. They can also select different image databases and different image features used for measuring the distance between two images.
- A retrieval result sample from the "car" image database is shown in Figure 2. Experiments show that users can get the query results in less than one second (server is SGI Indy), and the query results are close to human perception.

(a) (b) (c)



(d) (e)

Figure 2. Retrieval result sample. (a) The query image. (b)-(e) The similar images returned by the retrieval system. They are ranked by the color similarity measurement, with (b) having the highest rank.

CONCLUSIONS

In the paper, we presented the implementation of an image retrieval system in which color and shape information is used to assist image retrieval. Both browsing and query approaches have been implemented. The retrieval is fast and results are reasonably close to human perception.

REPORT BRIEF

Machine Vision Inspection of VF Display Boards

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
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ASSISTANT: Jie Chen and Tie-Qi Chen
Research Assistants

BACKGROUND

Vacuum florescent (VF) display boards are widely used in the automobile industry to display information about a vehicle's 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, it is critical for customer satisfaction that the display be of high quality. Once the circuit board is complete, the entire board must be tested for proper function. VF inspection consists of displaying and inspecting various patterns on each VS board that is produced. Currently, functional test operators visually inspect screen patterns during manufacturing. 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 on a given VF board. There are two major problems related to manual inspection:

- Currently, because of the time limit, an operator can inspect only two display modes, which is not enough to ensure the display board is functionally correct. Ideally every possible display pattern should be inspected. Currently, the number of display combinations that can be inspected is limited by the speed of the human inspector.
- 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 comprised 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 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., all of the components within the field are always in the same state, either all on or all off.

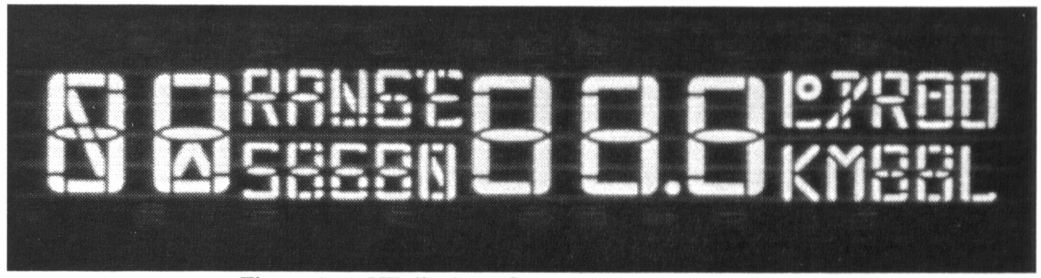

Figure 1. A VF display of compass/temperature/trip board

OBJECTIVES

The objective of this project is to develop computer vision algorithms and combine them with machine learning techniques for inspecting various VF display boards. These algorithms and techniques should:

- permit inspection of all possible display patterns without impeding product line rates
- eliminate human error in the inspection process

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.

Because of its diverse application environment, 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 2, which presents the overall view of the machine vision system designed for VF board on-line inspection.

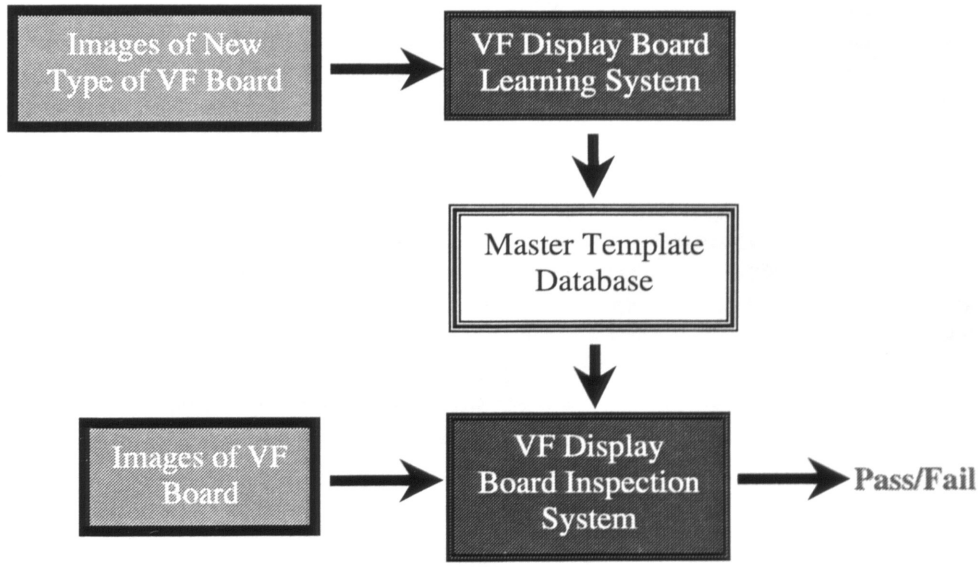

Figure 2

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 VF board on the production line, the inspection procedure will

generate 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 following subsections describe in more detail the learning and inspection procedures.

For a new type of VF board, the "learning procedure" is employed to learn the board features from a good compass board of the type, and the algorithm generates a symbolic representation of the compass board, which is referred to as 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 lines 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 Window NT/95/3.1x operating system. The learning subsystem has been deployed at Jabil Circuit, Inc., and the test subsystem 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 inspection procedures. The machine vision system is robust enough for a plant environment where lighting condition can vary and shadows can occur in images, and the testing boards can be tilted and be placed in various positions. During the off-line learning process, 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 boards. The inspection procedure is performed on the production line. Therefore, the inspection procedure is designed to be extremely efficient in computational time.

IMPACT

This 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, both of which ultimately lead 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

3-D Imaging Visualization and Tools

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
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ASSISTANT: Jin Deng
Graduate Student Research Assistant

BACKGROUND

Increased industrial automation plays a critical role in revitalizing America's manufacturing competitiveness. Machine vision is a key technology due to its potential to allow automatic inspection, process monitoring, and advanced robot guidance. For image processing and vision technology to be successfully integrated into operational processes, it is important to adapt the technology in a task-specific environment in a manner that requires little effort and a relatively short development time. In industrial settings, the expenditure of resources (cost and time) in employing imaging technology should be a relatively small portion of the total expended on automation processes. Therefore, the feasibility of applying imaging and vision technology to operational processes is dependent on having easy-to-use tools to design the systems.

Our research project is focused on building easy-to-use 3-D image processing software tools. The development platform is a personal computer using standard OpenGL library.

OBJECTIVES

1. Build a feature extraction tool with emphasis on 3-D range image applications in manufacturing processes.
2. Build a library that integrates the feature extraction algorithms with image processing and analysis methods/algorithms.
3. Develop an application platform with our industrial partners for manufacturing process control.
4. Reduce the commercial application development time based on the software environment and libraries.

APPROACH

We have collaborated with Perceptron to better understand industry needs and have applied for additional funding from the National Institute of Standard and Technology's Advanced Technology Program to expand the project to include the development of 3-D range data tools for industrial automation applications.

Our approach included the development of the following tools:

1. A user-friendly 3-D graphic user interface

2. Algorithms and image processing libraries:
    - Image filtering library
    - Morphological processing library
    - Feature extraction library
4. Advanced 3-D image processing development tools

RESULTS

LOOKNT, an industrial application-oriented software developing environment for image processing and machine vision, was developed. It provides many useful features for researchers and algorithm developers working in the field of image processing, machine vision, pattern recognition, and so on:

- A graphic user interface development environment
- Tools for image manipulation
- Algorithm development environment

CONCLUSIONS

This project has achieved three goals:

1. A user-friendly 3-D image visualization and processing tool was developed.
2. Useful algorithms and a set of helpful libraries were integrated into the 3-D image processing tool.
3. The application can be easily enhanced for further development and new feature expansions.

IMPACT

1. Faculty Enhancement: Collaboration with the industrial partners for this project has enabled the principal investigator to remain current with industrial trends in vision technology developments. Machine vision must draw upon industrial practice and applications to grow and expand. While the fundamentals of machine vision may be well understood in academia, vision design/development tools must be developed in conjunction with industrial applications to ensure their usefulness.

2. Engineering Curriculum: The results from this project have been introduced in courses related to the project contents. The algorithms will be included in classes related to image processing and machine vision. The results will also be used in engineering education programs, particularly a new course in applied machine vision, which is targeted at engineers who have some knowledge in imaging but need further education on applying imaging to solve manufacturing problems.

3. Participation with Industry: This project has generated some interesting results that were found useful in industrial applications. Perceptron was particularly interested in collaborating with us to study ways to effectively develop algorithms for automated inspections.

4. Education: One graduate student research assistant has been participating in this project and has been supported by the funding from the industrial partner and internal funding. A group of undergraduate students will participate in the research as summer interns sponsored by the National Science Foundation's Research Experience for Undergraduates Program.

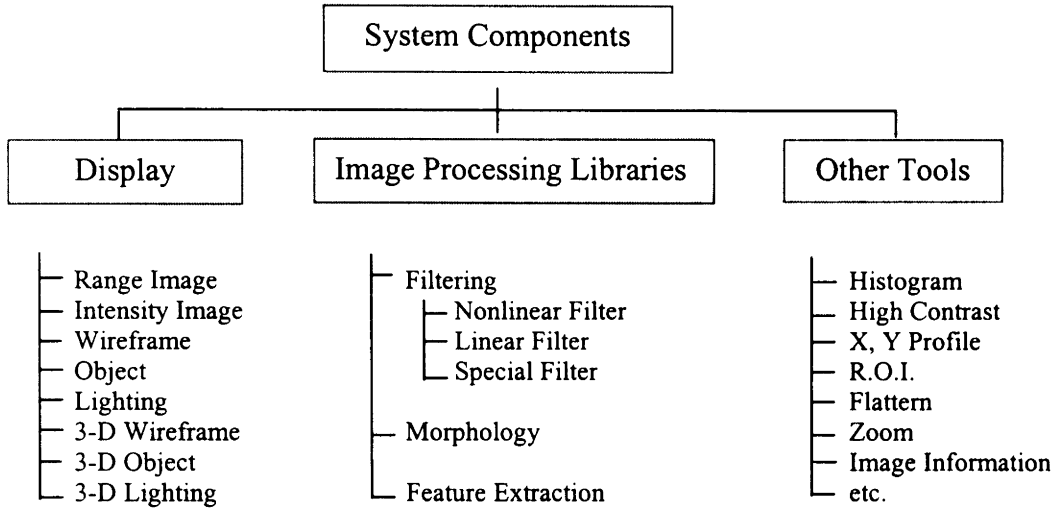

Figure 1. The system components diagram

The 3-D image processing application system was developed based on the following objectives:

1. Easy-to-use graphic interface
2. Display different formats of 3-D images and display 3-D image through different ways
3. Construct and collect various kinds of algorithms and image processing libraries for 3-D images
4. Realize basic and advanced image visualization and processing tools
5. Easily enhance for future development and new feature expansions

Department of Industrial and Manufacturing Systems Engineering

REPORT BRIEF

An Intelligent Tolerance Design Advisor for Injection Molded Parts

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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ASSISTANTS:	Xin-yu Shao and Quan Wen Research Assistants

BACKGROUND

The philosophy of design for manufacturing (DFM) states that a part should be designed by taking both functional and manufacturability concerns into consideration. In order to provide part designers with sufficient knowledge of manufacturing, attempts have been made to develop intelligent design advisors integrated with CAD systems. However, in most of the existing design advisor systems, a tolerance design function has not been included. This is particularly true for injection molded parts where tolerance design considerations are more complex. At Visteon Automotive Systems, emphasis has been put on the development of a design advisor for injection molding under the DFM environment. The inclusion of tolerances in design is one of the bottlenecks of their system. This project enhances the design advisor by providing a tolerance design module. This work has been funded by CEEP, REEDF, and Visteon for two years.

OBJECTIVES

1. To develop methodologies and a computer module that can perform the primary tolerance design and evaluation tasks for injection molded parts
2. To acquire, represent, and integrate tolerance-related knowledge from both design and manufacturing areas
3. To develop strategies and algorithms of tolerance optimization by considering both tolerance manufacturability and costs
4. To integrate the tolerance design module with the design advisor

APPROACH

1. A modularized method for developing main function models as well as the linkages among them
2. Multi-level classification of design and manufacturing-related factors, as well as hierarchical knowledge structure to support decision-making of tolerance design and evaluation
3. Fuzzy decision method to represent empirical knowledge and support trade-off decision making with uncertainty

4. Multiple optimization approaches including Taguchi method, design of experience, and integer programming to achieve tolerance optimization

RESULTS

1. The overall system structure for the tolerance design and evaluation module was improved, as shown in Figure 1.

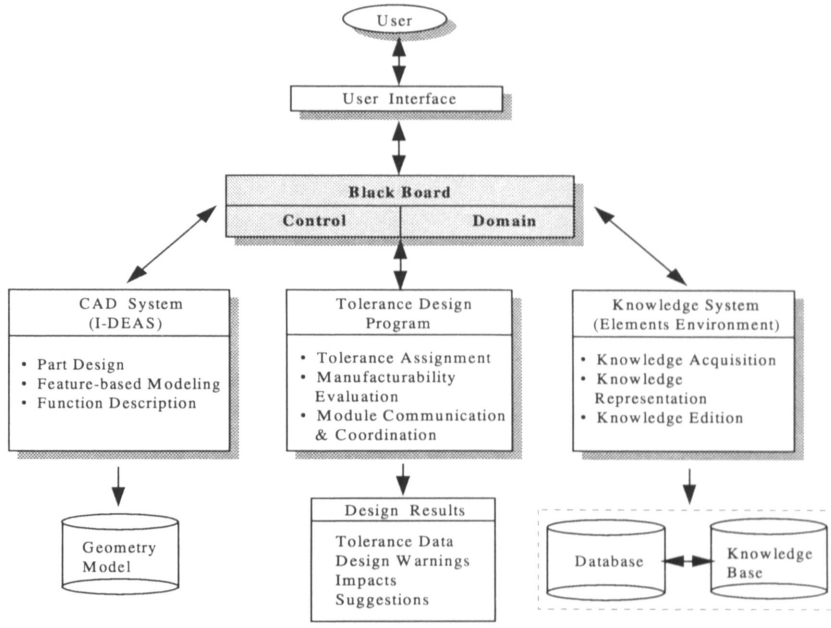

Fig. 1 The system structure of the intelligent tolerance design advisor

2. A prototype of the tolerance design and evaluation module has been developed. Figure 2 shows an example of the output result from the module.

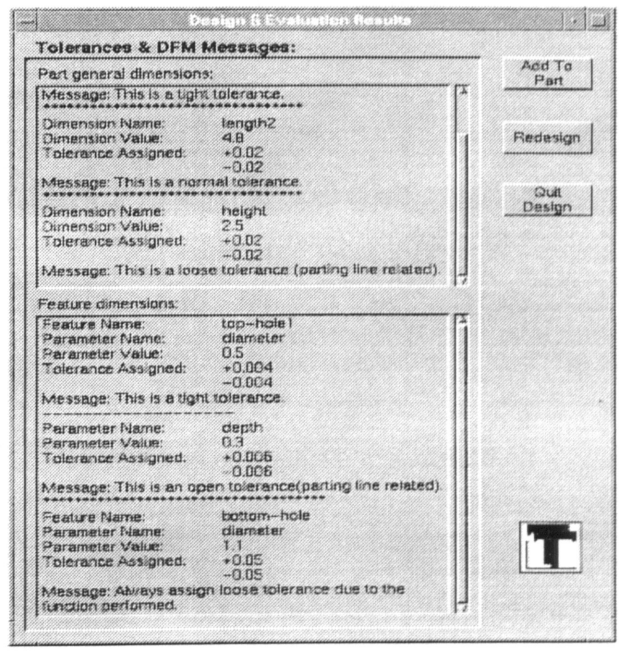

Fig. 2 The tolerance design and evaluation result

3. A knowledge base which collects rules related to several different tolerance design factors has been established.
4. A document entitled "Guideline of Tolerance Design for Injection Molded Parts" has been completed and submitted to Visteon for review. The guideline will be put on the Visteon/Ford Intranet.

CONCLUSIONS

1. Tolerance design for injection molded parts is different from that for metal cutting parts. It can be affected by a number of factors. A better design can be made based on information not only from design standards, but also, more importantly, from experts' experience.
2. Part modeling is still a key issue for tolerance design. The feature-based model can represent not only the part's geometric design and tolerance (GD&T) information, but also manufacturing requirement information. It has more advantages if used under a DFM circumstance.
3. A multi-classification 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. The long cycle from design to redesign can be avoided, and significant cost savings will be achieved.

IMPACT

The methodologies and technologies developed from this project, such as system structure, part feature definition, and multi-level classification scheme can be easily adopted for other industrial applications. The concepts and technologies involved in this project can also be integrated into our engineering curriculum, such as undergraduate design courses, or as thesis topics for the graduate program. Currently a Ph.D. student and a master's student are working on this project. The software packages used in this project, including I-DEAS 6.0 and Element-Environment 2.0, represent the latest CAD and knowledge-base technology, and are currently used by companies such as Ford. This project is impacting education by providing faculty and students with the opportunity to experience advanced tools for engineering design and knowledge processing.

ACKNOWLEDGMENT

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

REPORT BRIEF

Integration of Robustness and Reliability Engineering for Product and Process Improvement

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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ASSISTANT:	Wei Shen Graduate Student Research Assistant

BACKGROUND

It has been recognized that quality can be significantly improved at an early design stage if appropriate quality engineering methods are used. Robust design and reliability modeling techniques have been widely regarded as effective quality engineering tools. A lot of research has been done in these fields. However, these tools are developed separately without integration of the robust design and reliability principles. In addition, there is no generic model or practical procedure for implementing such technology into design and manufacturing processes. This deficiency significantly limits the application of robustness technology in industry. The goal of this project is to develop a practical improvement procedure for industrial systems, such as a robot.

OBJECTIVES

1. To develop a methodology for product/process improvement through the integration of robustness technology and reliability engineering
2. To develop a robust reliability model for education and industrial implementation

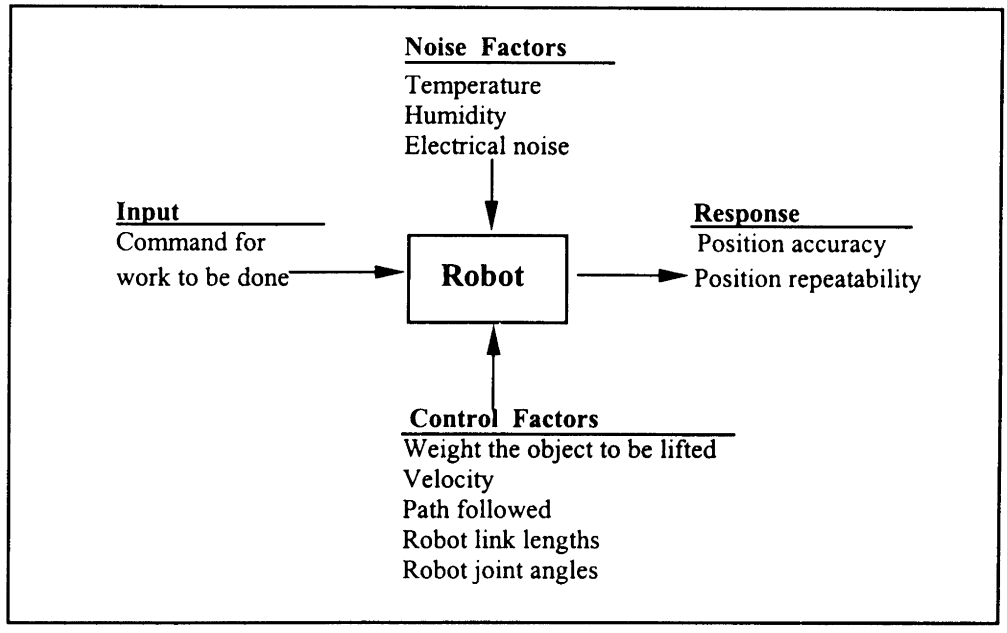
APPROACH

1. Investigation of various robust design and reliability modeling methods. A robot system is used.
2. Identification of key parameters that affect reliability based on the experiment test and data analysis. The design of experiment (DOE) method and the Taguchi method will be used and a comparative study will be carried out.
3. Development of a practical procedure for reliability testing, including establishment of the sensory and signal processing requirement
4. Development of the software package for the implementation of the methodology
5. Integration of existing techniques with innovative methods

RESULTS

1. A thorough literature survey of the available techniques of robust design and reliability modeling has been carried out.

2. A failure mode and effect analysis (FMEA) model was constructed. Based on this model, analytical study and experimental tests are being planned to further identify the important factors.
3. The potential factors that might affect the positional accuracy of the robot have been identified, which include:
    - Environmental factors: temperature, humidity, and electrical noise
    - Parametric factors: robot link lengths, joint angles, and non-linearity
    - Measurement factors: robot path computation errors
    - Computation factors: robot path computation errors
    - Application factors: installation errors and part presentation errors
4. The P-diagram (shown below) and cause and effect diagram of the robot have been constructed.



5. An experiment layout has been designed according to the P-diagram. The following design and data analysis methods will be used in the study:
    - Fractional factorial design
    - Orthogonal arrays
    - Signal-to-noise ratio methods
    - Response surface method
6. The robot accuracy and repeatability test procedure for the SCORBOT-ERV (a robot in the manufacturing systems engineering laboratory at UM-Dearborn) has been finished based on the ISO standard. Test units, coordinate system, conditions, robot positions and path, and the way to calculate accuracy and repeatability are specified in this plan.
7. Different tools and methods for the robot measurement have been evaluated.

CONCLUSIONS

1. Out of the available methods for robust design, the two methodologies that will be used for identifying the important control and noise factors affecting the positional accuracy of the robot are:
   - Statistical method using fractional factorial design, Log σ and RSM
   - Taguchi method using orthogonal arrays and S/N ratio
2. The failure mode and effect analysis (FMEA) model is an effective tool to find the criticality level of the failures.
3. The P-diagram and cause and effect diagram are very useful to identify the key factors that might affect the accuracy of the robot. Some of these factors will be further tested using the design of experiment method.

IMPACT

This research will benefit both industry and the university. Results of this project are directly related to industry needs since robust design and reliability improvement is one of the most effective tools for higher product quality and customer satisfaction. Funds from Visteon will support the internship students at Ford. The REEDF fund will be used to support the research activities at UM-Dearborn. Thus a long-term, sustainable cooperative program will be established between the university and industry. In addition, the methods and technologies involved in this project can also be used in education, such as the graduate course IMSE 513.

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REPORT BRIEF

A Genetic Approach Methodology for Knowledge Acquisition for Intelligent Diagnosis

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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ASSISTANT: Ron Wang
Graduate Student Research Assistant

BACKGROUND

An intelligent diagnosis system (IDS) for automated equipment is highly in demand because of the following advantages:

1. Availability: It is always available.
2. Perpetual: It maintains knowledge permanently.
3. Synthetic: It synthesizes knowledge from different experts.
4. Effective and efficient: It provides more accurate diagnosis in less time.
5. Flexible: Knowledge is constantly updated.
6. Cost efficient: Once implemented, it only requires cost for maintenance.

The success of any IDS depends on the quality of its knowledge, reasoning methodologies, and supporting database. Knowledge acquisition becomes the bottleneck to developing such systems.

OBJECTIVE

The objective of this project is to develop a self-learning system to alleviate knowledge acquisition bottleneck. The project is based on genetic algorithm (GA) and design of experiment (DOE) methodologies to collect sample failure data and extract rules from the data. Although a robot is selected for analysis, the system will be easily expanded to acquire diagnosis knowledge for other equipment.

APPROACH

The methodology employed for the system (a genetic algorithm) is based on the evolution theory. It is composed of population, operators (reproduce, crossover, and mutation), fitness function, and system parameters. GA population consists of chromosome structures where each chromosome represents a solution to a certain problem. *Reproduce operator* selects the individuals that have a higher chance of survival. *Crossover* interchanges part of the chromosome with a certain probability between different individual chromosomes. *Mutation* changes attributes within an individual chromosome. *Fitness* is the criteria determining whether an individual would fit in its environment or not.

In this project, 13 exogenous variables form the symptoms according to the movement of the robot arm (12 movements in cartesian and joint modes and the HOME position). Each variable has two status, "0" as normal case and "1" indicates errors observed in the

movement. The cause can be any one of the 17 possible faults (six motors, six encoders, and five micro switches). Each possible cause also has two statuses: "0" represents the part in normal condition and "1" indicates the part in faulty condition.

With 17 possible causes of failures, the set of fault scenarios could reach up to 2^{17}-1= 131071 combinations. Different combinations of faults could generate the same symptom. Hence, only a portion of scenarios is required. Design of experiment (DOE) technique is used to determine the total number of data points and how they should be collected. Each data point is collected by simulating the robot's arm with some faults set according to the experiment design. The collected data set is randomly divided into the training set (80%) and the test set (20%). For each possible cause, this division is repeated five times. Each time the system will capture rules from the training set by applying a specific GA model. Then the integrity of the GA model is evaluated by testing it against the test set and by utilizing the average fitness as a measure of the model integrity. The average of the results from the five divisions yields the evaluation of this specific GA model as applied to the fault cause. GA has the capability that its paradigm and parameters could be set towards a specific problem. Therefore, different models are analyzed and compared for selection of the best one. In this study, five paradigms are used, which are summarized in Table 1. In addition to these paradigms, three parameters are also concerned. They are Crossover Rate, Crossover Point (how many points in a chromosome can be crossovered), and Elitism (percentage of the population considered to be "good solutions"). Crossover rate has four levels (0.6 – 0.9, with 0.1 step), crossover point has 15 levels (1-15), and elitism has three levels (0.1, 0.14 and 0.18). The paradigms and parameters form 5*4*15*3 = 900 different models. All these 900 models are trained and tested for comparison.

The evaluation results of 900 GA models are used to determine which paradigm or parameter contributes most to the fitness. They are used as inputs to MINITAB for the analysis of variance (ANOVA) for selection of the best paradigm and parameters. The best model performs learning using the whole data set. The rules extracted become the knowledge. Validation ensures that the rules generated are true representations of the system. New scenarios independent of the previous scenarios are collected. The extracted rules are tested against these new scenarios. A high fitness is the indicator of the success of the knowledge acquisition system.

RESULTS

The system is implemented using Borland C++, with a user-friendly interface. A typical learning procedure is illustrated in Figure 1.

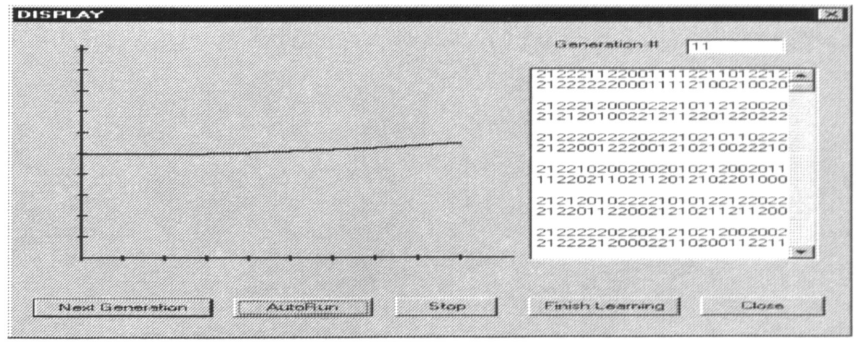

Figure 1. GA learning procedure

In Figure 1, the list box to the right presents all the individuals within a population, while the left side diagram reveals that the average fitness of the population is going up along time axis.

The results from ANOVA are as follows:

- Diploid chromosome paradigms are better then single chromosome paradigm. Among diploid chromosome paradigms, the Diploid-Non-Dominance-Non-Gender paradigm is the best one.
- Small multiple crossover point (2-3) is superior.
- Crossover rate and elitism factors are not significant in contributing to the fitness.

Based on these results, the best GA model for the robot diagnosis analysis is: Diploid chromosome-Non-Dominance-Non-Gender paradigm with crossover rate 0.6, elitism factor 0.14, crossover point 2. Sample rules generated from the analysis are listed in Table 2.

CONCLUSIONS

This project applies genetic algorithm to extract knowledge from previous failure data. It automates the knowledge acquisition procedure and alleviates the knowledge acquisition bottleneck. Previous failure data are adequately sampled using DOE technology. Different GA models are developed for selection of the best one. The best GA model extracts the final rules. The results from the system demonstrate the general improvement along the learning procedure; Diploid-Non-Dominance-Non-Gender GA paradigm with crossover rate 0.6, elitism factor 0.14, and crossover point 2 is proved to be the most suitable model for robot diagnosis knowledge learning.

IMPACT

This research possesses high value for both education and industry. For education, this project applies genetic algorithm, an efficient and effective machine learning method, to generate knowledge for robot diagnosis. Genetic algorithm has infrequently been applied in this domain. For industry, although the robot was chosen as a typical application to illustrate the capabilities of the technique, the system is easily adapted for knowledge acquisition for diagnosing other equipment. Only redefinition of symptoms and causes is required. The knowledge extracted can also be implemented into the knowledge base for an intelligent diagnosis system.

Table 1. Summary of different paradigms

Population Type	Population Name	Description	CrossOver Operator	Fitness Function [1]
1	Single chromosome	An individual has only one chromosome	Normal crossover is applied. The crossover points range between 1 and ½ length of the chromosome.	f(g)= (Pg+N-Ng) /(P+N)
2	Diploid-non dominance-non gender	An individual has two chromosomes. Crossover can be of same or different gender.	**For single point crossover,** the two parents exchange one chromosome with each other. **For multiple point crossover,** the two parents each provide one chromosome to form a new individual and then normal crossover is executed on the two chromosomes within this new individual.	Apply f(g)= (Pg+N-Ng) /(P+N) to both chromosomes. The average of the two is the final fitness of the individual.
3	Diploid-dominance-non gender	An individual has two chromosomes. Crossover can be of same or different gender.	**For single point crossover,** the two parents exchange one chromosome with each other. **For multiple point crossover,** the two parents each provide one chromosome to form a new individual and then normal crossover is executed on the two chromosomes within this new individual.	First decide the "dominant style" of the individual. Apply f(g)= (Pg+N-Ng) /(P+N) on this dominant style.
4	Diploid- non dominance-gender	An individual has two chromosomes. Crossover can only be of different gender.	First select a "male" and a "female" to be parents, then: **For single point crossover,** the two parents exchange one chromosome with each other. **For multiple point crossover,** the two parents each provide one chromosome to form a new individual and then normal crossover is executed on the two chromosomes within this new individual.	Apply f(g)= (Pg+N-Ng) /(P+N) to both chromosomes. The average of the two is the final fitness of the individual.
5	Diploid-dominance-gender	An individual has two chromosomes. Crossover can be only of different gender.	First select a "male" and a "female" to be parents, then: **For single point crossover,** the two parents exchange one chromosome with each other. **For multiple point crossover,** the two parents each provide one chromosome to form a new individual and then normal crossover is executed on the two chromosomes within this new individual.	First decide the "dominant style" of the individual. Apply f(g)= (Pg+N-Ng) /(P+N) on this dominant style.

[1]Fitness Function: f(g)= (Pg+N-Ng)/(P+N)
where g: an individual (a learned rule).
P: the positive example number that the whole data has for a specified motor /encoder /microswitch. (**Positive example:** when learning rules about a specific fault, all of the examples corresponding to that fault are treated as positive examples. **Negative example:** the rest of the examples in the data set.).
N: the negative example number that the whole data has for a specified motor /encoder /microswitch.
Pg: the positive example number that g covers within P.
Ng: the negative example number that g covers within N.

Table 2. Sample rules learned for different faults

Faults	**Rules Learned (String)**	**Rules Learned (Standard Format)**
Motor 1	1122121202221	**IF** X, Y and Roll movements in catasian mode **and** Base movement in joint mode are faulty, **but** Elbow movement in joint mode is normal **and** Home function is faulty, **THEN** Motor 1 is malfunctioning.
Motor 3	1121222212122	**IF** X, Y and Pitch movements in catasian mode **and** Elbow and Roll movements in joint mode are faulty, **THEN** Motor 3 is malfunctioning.
Encoder 4	2222112221121	**IF** Roll and Grip movement in catesian mode are faulty **and** Pitch and Roll movement in joint mode are faulty **and** HOME is faulty, **THEN** Encoder 4 is malfunctioning.
Microswitch 3	2122212212111	**IF** Y and Grip movements in catesian mode are faulty **and** Elbow, Roll and Grip movement in joint mode are faulty **and** HOME is faulty, **THEN** Micro switch 3 is malfunctioning.

REPORT BRIEF

Modular Design Methodology for Parallel Sub-System Design

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

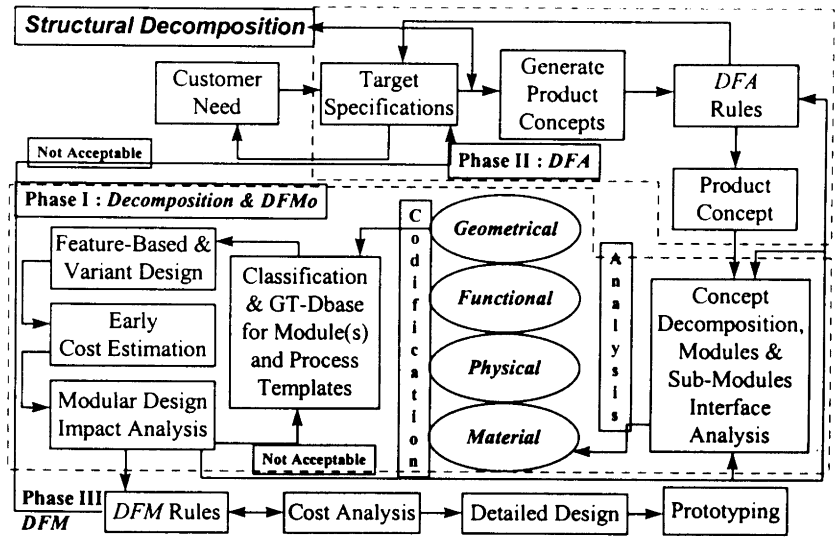
Modular design is an engineering methodology that organizes and structures a complex product, process, or system into a set of components or activities that could be developed independently of each other and then assembled together. Modular design can be defined as a process that decomposes a design problem into parts that are as independent from one another as possible, and therefore attempts to create standard components which could be used in a wide variety of application with little or no modification. Modular manufacturing is a manufacturing analog of modular design in which manufacturing processes are decomposed into independent subsets that can be easily adapted for new applications.

OBJECTIVE

Develop a systematic approach for modular design to offer product architecture selection by establishing a design decomposition, which identifies and reduces the interaction among the modules to reduce the design complexity.

APPROACH

A three-phase methodology is proposed for the development of complex products using modularity concept. The proposed methodology matches the criteria set by the design for functionality, assembly and manufacture. The enabling technologies for this design environment are knowledge-based engineering (KBE), group technology, clustering, and mathematical modeling. The concept applied to the methodology includes system engineering and product information management. The steps associated with this methodology include decomposition analysis (design for modularity and classification), product analysis (design for assembly and functionality), and process analysis (design for manufacture).



In order to implement this concept successfully, the manner in which the modules are selected is critical. By establishing simple interfaces within the modules, the numbers of interactions are then reduced. Phase I of this methodology is the focus of this project. Additional specifications associated with this phase include:

- Engineering design specification (EDS) based on functional requirements (FR)
- Decomposition and impact analysis
- Associativity analysis between the product design and features
- Identification of independent components

RESULTS

A highly disciplined and scientific systematic approach for modular design was developed. The developed approach applied systems engineering concepts and cross-functional team participation. The resulting approach identifies the independent modules and their interfaces. The resulting modules can be designed in parallel while emphasizing the existing interactions. This will organize the design process in such a way that the design cycle time is reduced; it will also offer product architecture selection based on functional and physical factors.

CONCLUSIONS

The major objective of the modular design approach is to develop independent and standard components that could migrate from one product design to another. A systematic approach for modular design was developed to offer product architecture selection based on functional and physical factors. The approach identifies components that can be developed in parallel, which will increase design efficiency. Also, the approach identifies the interfaces between components in different modules. This can be used to simplify the interactions between components and increase the reusability of the designed components.

IMPACT

A thesis entitled "Modular Design Approach for Gear Drive System" for a master's degree in industrial and manufacturing systems engineering was offered and the student was supported throughout the phases of this project. A new course was developed (IMSE 589, Product Design and Rapid Prototyping). Modular product design is a major part of this course, since it allows for structure approach for problem and product design decomposition.

Four external proposals were developed and two of them were funded for a total of $50,000. The industrial partner has decided to further study this concept in design of facility, known as modular facility and production system.

ACKNOWLEDGMENT

The principal investigator wishes to thank Mr. Peter R. Sferro and Mr. Ken Kuna of Ford Motor Company for their support of this project.

REPORT BRIEF

Fuzzy Inference System (FIS) Based Decision-Making Algorithms for CMM Measurement in Quality Control

June 24, 1998

STATE OF MICHIGAN RESEARCH
EXCELLENCE AND ECONOMIC DEVELOPMENT FUND

COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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BACKGROUND

The sampling strategy for a CMM inspection process is a property of the operator, while the accuracy level is a property of the machine itself. Advancements in hardware technology over the last few years allowed for the production of a new generation of CMM machines that are capable of high-precision measurements, yet the inspection quality of these machines is impaired by improper sampling strategy. This research work concentrated on the development of a fuzzy-logic-based decision-making system as a means for soft computing for CMM sampling strategies. This project introduces the use of fuzzy logic to relate the machine tool accuracy to the part measurement accuracy and to make a knowledge database that contains machine tool accuracy and part accuracy to be used for prediction of the sampling strategy for subsequent parts. This project was funded by REEDF.

OBJECTIVES

The objectives of this project are as follows:

- Establishment of a knowledge base containing design data, machine tool accuracy, and CMM inspecting experience
- Development of methodologies and algorithms for mapping the data in the knowledge base to CMM sampling strategies
- Development of algorithms for a feedback loop that performs on-line updating of the knowledge base and the decision-making rules
- Implementation of the software for the aforementioned knowledge base, methodology, and algorithms in a manufacturing facility

APPROACH

Technical approaches used in our project are:

- System architecture and information channels
- Theory and methodology for decision-making module
- Establishment of a knowledge database through experiments
- Development of fuzzy inference methodology and algorithm associate system for the improvement of CMM measurement accuracy and productivity
- Simulation and experimental verification

RESULTS

Figure 1 is a diagram of the decision-making system. Based on fuzzy inference methodology, the decision-making engine accepts input data and information from related databases. The components of the system are: (1) knowledge databases, (2) fuzzy inference based decision-making engine, (3) on-line feedback and adaptation (FBA) module, and (4) feature fitting software (FFS).

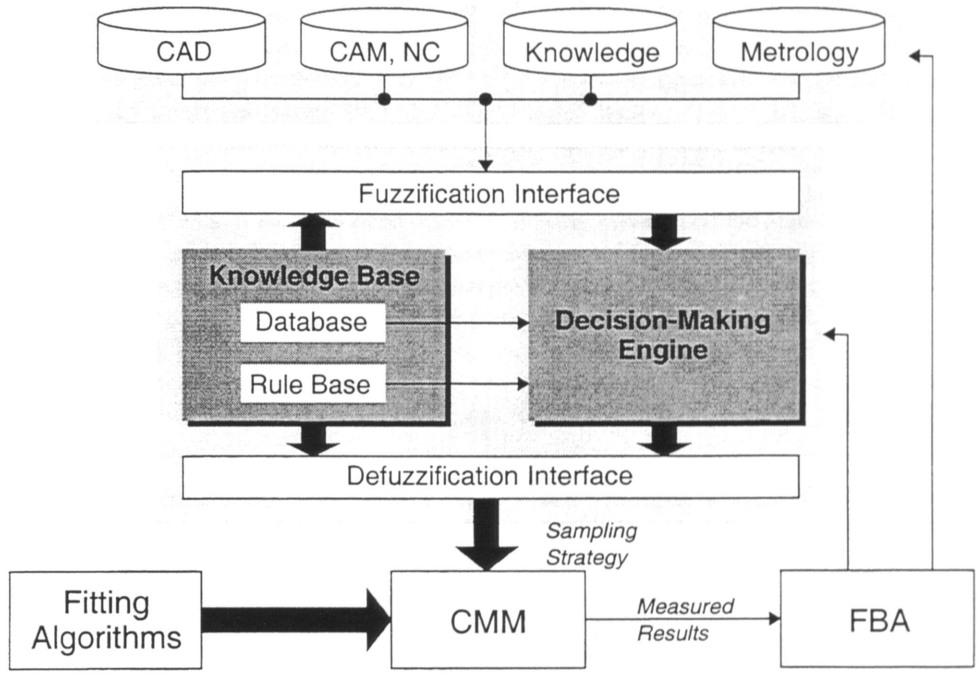

Figure 1. Overall Diagram of the Fuzzy Decision-Making System

1. Knowledge Databases: The knowledge databases are collections of the information and data related to design, manufacturing, metrology methods, and previous experience. Accordingly, the information and data are to be imported to the decision-making module. It is the premise of the prediction of the CMM sampling strategy.
2. Decision-Making Module (DMM): The DMM implements a nonlinear mapping from its input space to the output space with CMM measurement strategies for particular geometric features on a machined part. This mapping is accomplished by a number of fuzzy "IF-THEN" rules, each of which describes the local behavior of the mapping technique.
3. On-Line Feedback and Adaptation (FBA): Supervised by the exported strategies from DMM, the CMM will probe the data points at specific locations on the part surface as proposed by the measuring strategies. Meanwhile, the coordinates of the inspected points are monitored by the FBA module. These on-line data, together with the related data in the knowledge database, are processed in the FBA module in order to determine the feasibility and practicality of the decisions made by the system.
4. Feature Fitting Software (FFS): An FFS has been developed to fit the measured points to a geometric feature and to determine the feature parameters and form errors. A software package has been developed by the authors through the course of this project for CMM fitting algorithms for several geometric features including lines, circles, planes, and cylinders.

CONCLUSIONS

- The framework of a fuzzy-logic-based decision-making system consisting of the aforementioned modules has been accomplished. Proper CMM measurement strategies will be made and exported to the controller of CMM to realize desired measuring activities of the machine. The on-line feedback and adaptation module enables the system to possess self-learning capacity, which is believed to be effective in improving the accuracy and practicality of the decision-making system.
- Several methodologies, algorithms, and techniques for the fuzzy decision-making system have been initialized. These include (1) normalized error model of surface features, (2) data processing methodologies, (3) fuzzification and defuzzification techniques, and (4) fuzzy inference system (FIS) for the decision-making engine. Utilizing these algorithms and methods, the decision-making system will be able to map the inputs in the knowledge base into the output of the CMM measurement strategies.
- The applications of the initialized decision-making system and the algorithms have been applied by means of experiments and simulations. A CNC machine was used to machine the test blocks to simulate mass production on a modern manufacturing floor. A high-density sampling was performed on the machined part to get an accurate measurement of the surface. The appropriate data analysis was performed for the normalization and standardization of the data to be ready for use by the decision-making system. The results obtained from our decision-making system for the test part proved very promising.

IMPACT

Based on our conclusions, it is believed that the methodologies developed from this project can be implemented for industrial applications after further development of the system to incorporate more features to enhance its performance and capacity. This would be done through more experiments to enhance the knowledge databases and increase the level of sophistication of the rules and the decision-making system.

The work done on this project involved the use of many engineering concepts from the field of manufacturing engineering and can be readily integrated in some of the engineering curriculum courses. Furthermore, the software packages used and developed during the course of this project are helpful tools that are already in use by engineering students.

Department of Mechanical Engineering

REPORT BRIEF

Experimentation and Simulation of Drivelines Containing Composite Shafts

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Mechanical Engineering

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General Motors

ASSISTANT: William Danos
Research Assistant

BACKGROUND

This work is an extension of ongoing research by the principal investigator on composite shafts funded by CEEP and is related to other projects funded by General Motors and the National Science Foundation. These projects focus on dynamic analysis methods for flexible composite driveshafts, experimental methods to characterize their damping, and composite shafts for high-speed machining processes.

Some of the ongoing research has suggested that some general driveline dynamic problems may be mitigated through the use of composite shafts. In the current research, driveline simulation and experimentation are being used to assess the effects of composite shafts on driveline vibration. In the first phase of the work, a physical bench model of a driveline has been constructed and used to simulate driveline vibration problems.

OBJECTIVES

The long- and short-term objectives of the work are to:

1. Develop flexible driveline vibration analytical tools to evaluate driveline systems
2. Build and vibration test a simple physical bench model of a driveline incorporating universal joints, shafts, sprung masses, and a torque resisting component
3. Characterize the physical model's propensity to exhibit driveline vibration problems
4. Devise and perform experiments to test the ability of composite shafts to mitigate these problems

APPROACH

The approach employed in this project is experimental and analytical.

RESULTS

A sketch of the physical model is given in Figure 1. The arrangement is fully dimensionally adjustable via bolt holes in the base. A specially constructed test stand at the right end allows variation of the universal joint angle. A sprung bearing mount has been designed

and fabricated to attach to the test stand. The device is also able to accept a variety of motors so that shafts can be driven into rigid and flexible instabilities.

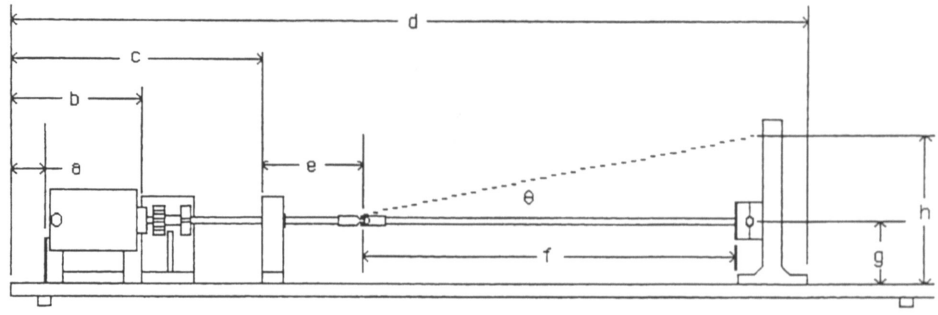

Figure 1

CONCLUSIONS

Tests were conducted on various shafts and under various geometrical arrangements. Some results are given in Figures 2 and 3 in which two types of instabilities that can occur in a driveline system are demonstrated. The system which produced the results has measured natural frequencies (ωn) of about 32 hz and 43 hz. The plots show the response of the system as a function of time when the shaft is driven at rotational frequency $\omega o = 21.6$ hz (Figure 2) and $\omega o = 43.1$ hz (Figure 3). It is well known that a universal joint having a nonzero joint angle generates forces and moments which vary nearly harmonically with frequency $2\omega o$. In a driveline, these effects have been found to produce the usual forced resonance (Figure 2) and, in addition, another instability called parametric resonance (Figure 3). Forced resonance occurs when the nonhomogeneous forcing terms in the system have a frequency coinciding with a natural frequency. So, here they occur when $2\omega o = \omega n$, as demonstrated in Figure 2 for the 2nd mode. Parametric resonances are due to periodically varying coefficients in the system and may be shown to occur here when $2\omega o = 2\omega n /j$, where j=1,2,3,... . The principal parametric instability occurs for j=1 and is demonstrated in Figure 3 for the 2nd mode. This instability is seen to grow to an amplitude which is about 10 times the forced resonance amplitude.

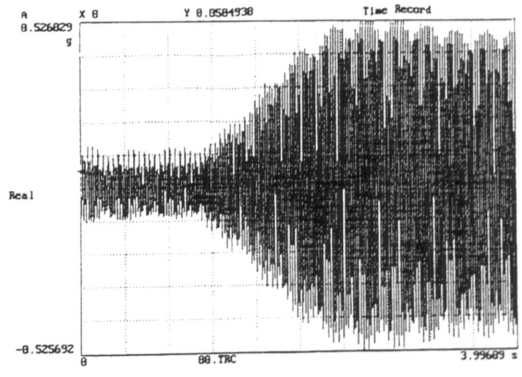

Figure 2

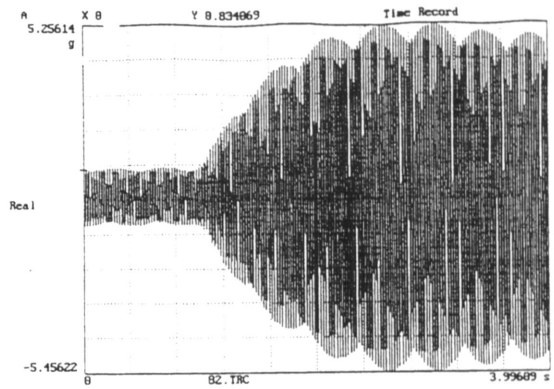

Figure 3

IMPACT

The model will be used to demonstrate, in a simple manner, various instability phenomena to students and practicing engineers.

ACKNOWL-EDGMENT

Various pieces of equipment have been loaned or donated by General Motors.

REPORT BRIEF

NVH Performance Improvement of Automotive Air-Conditioning Compressors

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Department of Mechanical Engineering

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Ford Motor Company

ASSISTANTS: Zheng Yu
Research Associate

BACKGROUND

The compressor is the most critical and expensive component of the entire air-conditioning system of a vehicle. Since 1992, Ford has been developing an advanced air-conditioning compressor (A/C compressor) called the VF2 (see Figure 1). The performance of the VF2 compressor has either matched or exceeded the performance of current market compressors, such as the Scroll compressor. However, the noise-vibration-harshness (NVH) performance of the VF2 compressor has been less than satisfactory. It generates higher air- and structure-borne noise levels than those produced by the Scroll compressor. Therefore, Ford is eager to find effective methods to solve this problem as soon as possible.

A research team has been formed consisting of faculty and researchers from UM-Dearborn and engineers from Ford. The mission of the research team is "to reach and sustain industry leadership position in A/C compressor noise and NVH abatement capabilities." This project provides a unique opportunity for the UM-Dearborn faculty to apply their expertise in NVH and structure dynamics to a real industrial noise and vibration control problem. At the same time, it also provides an opportunity for the Ford engineers to improve their analytical and experimental capabilities in acoustics, vibrations, and NVH controls.

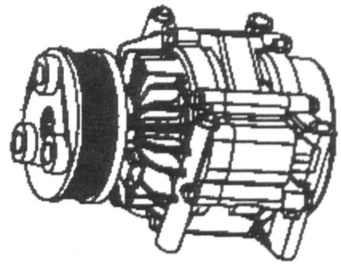


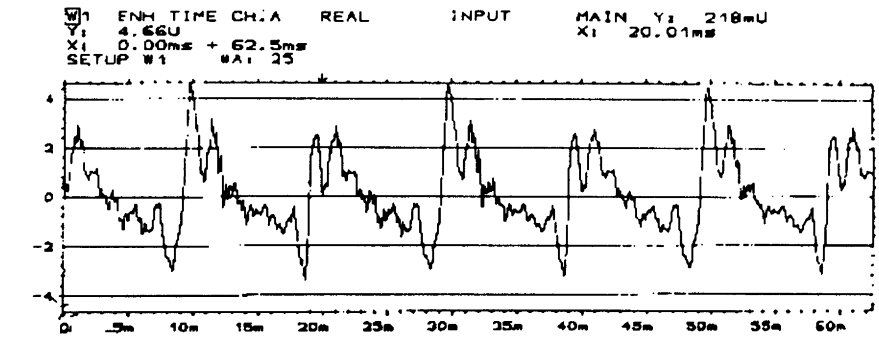
Figure 1

OBJECTIVES

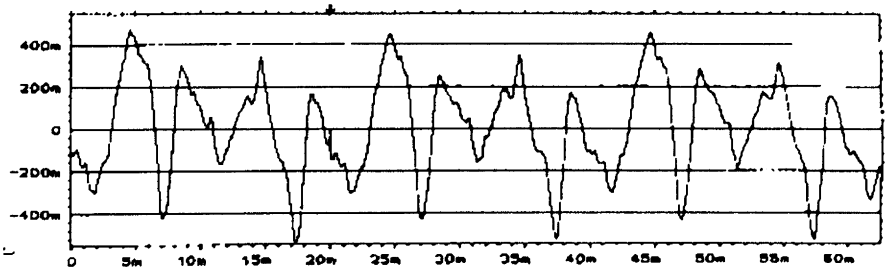
1. Characterization of the compressor's acoustic and vibration performance at both on-line inspection conditions and vehicle on-road operating conditions
2. Correlation of the acoustic and vibration performance of the compressor with its compression performance and its NVH on-road operating conditions
3. Development of mathematical models to determine the NVH sensitivity of VF2 compressors

APPROACH

Technical approaches include: (1) develop test methods, (2) identify signal analysis methods, (3) generate mathematical dynamic models of the compressor, (4) correlate and validate analytical and experimental results, and (5) implement and evaluate developed technology. Experimental results have shown that the pulsation of the refrigerant vapor controlled by the reed valve is the most dominant sources of air-borne noises [1]. A reed valve is a thin circular disc with stamped openings. The reed valve is used to separate the first stage from the second stage of the compressor. It performs as a check valve that allows the refrigerant vapor to flow only in certain directions through different portions of the disc. The noise is caused by the chattering of the reed valve, which is induced by the high-pressure vapor pushing through the valve and creating vortices and turbulence. Figures 2a and 2b present the time signals at the discharge and at the suction (2" from the port) of the compressor respectively. These periodic, sharp slope, and oscillating pressure signals indicate that the strong unsteady fluid flow is generated in the compressor. Characterization of this fluid-flow-induced noise requires both analytical models and experimental validation.



(a)



(b)

Figures 2a and 2b

IMPACT

It is believed that the techniques developed in this project can be easily adopted to the other mechanical systems as well as other industry fields. In addition, these technologies and concepts can be integrated into our current 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 ME 346 (Instrumentation and Measurement) course.

RESULTS

By completing this project, the following tangible results are expected: (1) Produce compressors that have low air- and structure-borne noise levels with optimum mechanical performance, and (2) Reduce air conditioning system costs by eliminating expensive mufflers in the current system (estimated savings: $6/system x 5 million units/year = $30 million/year).

ACKNOWL-EDGMENT

This project is jointly supported by the Center for Engineering Education and Practice (CEEP), the College of Engineering and Computer Science at UM-Dearborn, and Ford Motor Company. The authors deeply appreciate the cooperation and assistance provided by the engineers, namely Vipen Khetarpol, Himanshu Dalal, and Shane Harte, Advanced Climatic Control Division, and the staff and technicians of Ford Motor Company's compressor plant in Connersville, Indiana.

REPORT BRIEF

Sheet Metal Forming under Multistage Stamping Process

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Dr. Arthor Tang, Engineering Technology Associates
Dr. Norman Gjostein, Private Consultant

ASSISTANT: Dr. Wei-hua Tai
Research Associate

BACKGROUND

The formability of sheet metal is affected directly by the forming procedures. Most stamped parts or automotive components are produced by multistage loading processes. The forming limit strains induced during the actual forming operation are therefore path-dependent. However, most conventional methods of formability analysis for sheet metals are limited to proportional loading, thus resulting in prediction of path-independent limit strains. The principal investigator plans to develop a new predictive method capable of determining an optimum strain path for a particular manufacturing process before failure occurs. The method of analysis is based on a recently developed damage mechanics model of *forming limit diagram* (FLD), which will be extended to predict limit strains under multistage manufacturing processes, a prerequisite to developing an optimum strain path and manufacturing process.

OBJECTIVES

The primary goal of this research project is to develop a predictive method for path-dependent limit strains that can be used to design an optimum sheet metal manufacturing process for automobile parts. The development of such an optimum process requires knowledge of the formability of sheet metal for which the well-known FLD is widely used. Both theoretical and numerical simulations are carried out to gain a clear physical road map of multistage forming process.

APPROACH

The conventional method used to predict localized necking adopts two fundamentally different approaches. Under uniaxial and biaxial loading, Hill's plasticity method is often chosen when α $(= \varepsilon_2/\varepsilon_1) < 0$. The M-K method is adopted for the prediction of localized necking when $\alpha > 0$ or the biaxial stretching of sheet metal is pronounced. Both methods of prediction for FLD have not been found to be accurate. In addition, the M-K method suffers from the arbitrary selection of an imperfection size, which often results in inconsistent predictions. In view of the apparent deficiencies in the conventional methods of FLD prediction, a research project is to be undertaken by applying the theory of damage mechanics. Unlike the conventional method, which assumes that all sheet metals are "perfect" and free of defects in the form of micro-cracks/voids, the new theory takes into

account the effects of initiation, growth and coalescence of the micro-defects in "real-life" material up to its final rupture. Then a damage model will be developed and used to predict the FLDs of VDIF steel under multistage forming process. Also, the damage model will be implemented in a large-scale finite element package, LS-DYNA, which enables the numerical simulation of forming processes for a variety of automobile parts.

RESULTS

An approach based on an isotropic damage model has been successfully extended to predict the formability of VDIF steel under non-proportional loading. The damage model has also been implemented in the explicit finite element program LS-DYNA3D by developing a user-defined material subroutine. The program has been used to predict path-dependent limit strains for two complex stamping processes: (1) U-channel bending and uniaxial tension and (2) U-channel bending and biaxial stretching (Fig. 1 and Fig. 2). Computer simulation of three multistage forming procedures is carried out, from which the deformation profile of metal sheets (Fig. 3 and Fig. 4), the variation of strain-path experienced by the sheet element and the FLDs of VDIF steel (Fig. 5 and Fig. 6) are obtained. The effects of bending and unbending, multi-step loading and spring back on the formability are examined.

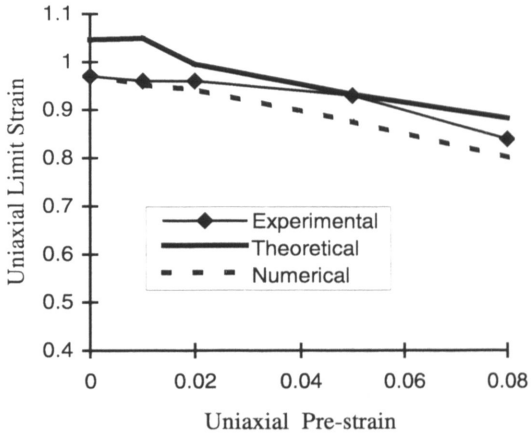

Fig.1 Uniaxial limit strain vs pre-strain

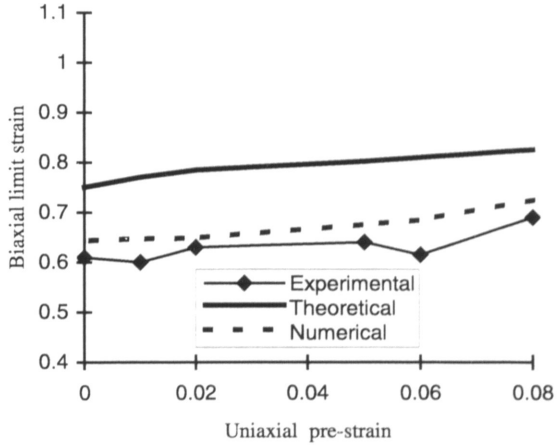

Fig.2 Biaxial limit strain vs pre-strain

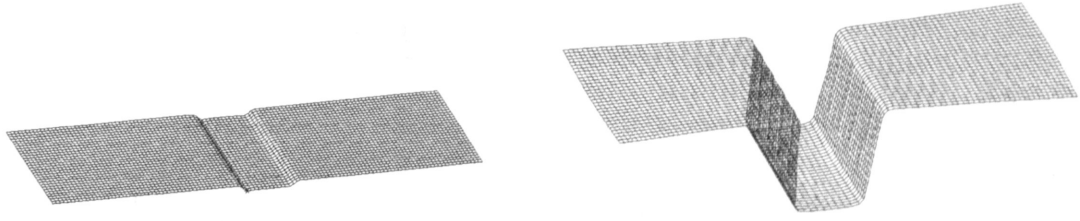

Fig. 3 Forming process of the U-channel

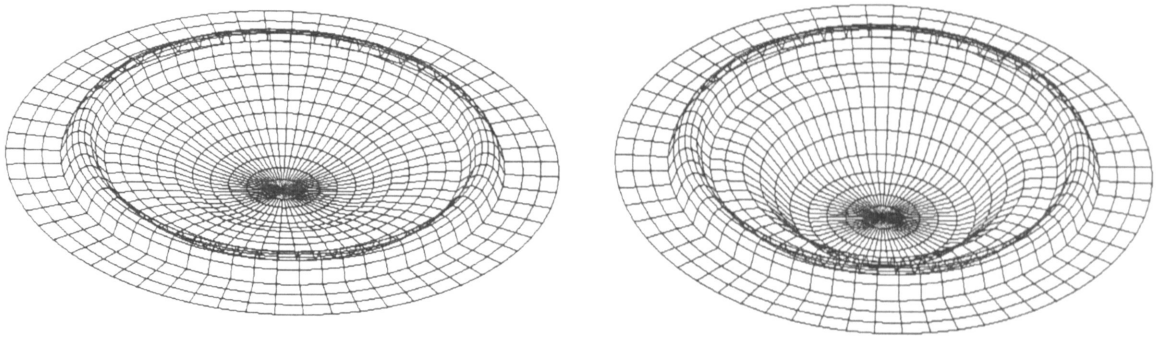

Fig. 4 Forming process of biaxial stretching

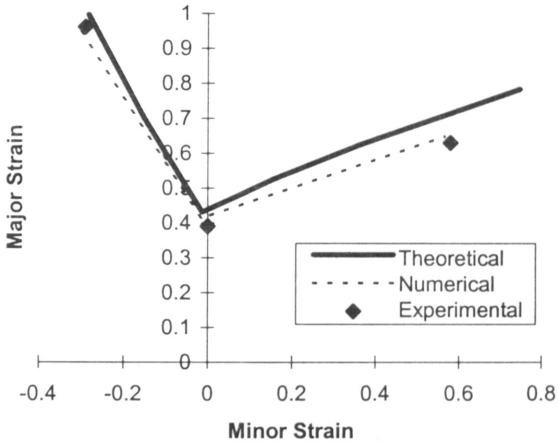

Fig. 5 FLDs for pre-strain=0.02

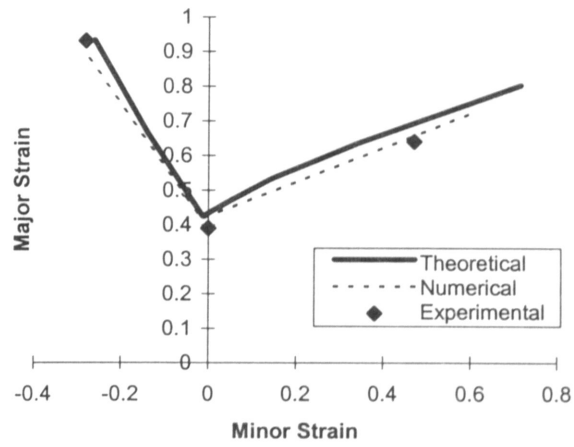

Fig. 6 FLDs for pre-strain=0.05

CONCLUSIONS

The anisotropic damage model has been extended to predict the formability of sheet metals under multistage stamping process. The model has also been successfully incorporated in a general purpose explicit nonlinear finite element code, LS-DYNA. Both theoretical prediction and numerical simulation of uniaxial and biaxial stretching operation are carried out for VDIF steel. The results show that:

- The proposed approach, based on a damage model, is proven to be more accurate than the conventional methods, as the effects of non-linear loading and change in strain path during forming operation can be taken into consideration. The damage model can be used to predict the FLD of either a single material element or a complex automobile part using the damage-coupled LS-DYNA.
- Computer simulation can provide an accurate and realistic prediction of the formability of stamped parts using the LS-DYNA program, because complete strain history in a stamped part can be readily calculated.
- The effects of bending and unbending, straightening, spring back and thickness of sheet can also be examined using the damage-coupled LS-DYNA.

- Computer simulation, based on the theory of damage mechanics, makes possible the optimization of sheet metal forming process in achieving maximum formability of sheet metals.

IMPACT

Neither the theory of damage mechanics nor forming limit analysis has been taught as a subject in mechanical engineering undergraduate or graduate courses. Because of the importance of the subject matter, an attempt will be made to introduce the concepts of damage mechanics into the curriculum.

REPORT BRIEF

Solder Joint Reliability Analysis under Thermo-Mechanical Loading

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Yi-Hsin Pao and Dongkai Shangguan
Ford Motor Company

ASSISTANT: Yong Wei
Research Associate

BACKGROUND

The Sn-Pb eutectic alloy is widely used as a joining material in electronics industry. In this application, the solder acts as both an electrical and a 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 causing reliability concern in solder joints. 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 thermo-mechanical loading for the constrained solder. The reliability of solder interconnections under thermo-mechanical 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 joints under thermo-mechanical loading. The methodology is based on the state-of-the-art technology of damage mechanics, which leads to a macroscopic description of the successive physical material deterioration phenomena.

APPROACH

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

RESULTS

The following results have been obtained:

1. A fatigue damage model has been developed for 60Sn-40Pb solder material.

2. A test program has been set up for the determination of material parameters.
3. Two sets of mechanical/damage parameters at room temperature under two different strain rates, 10^{-3} and 4×10^{-3} /s, were measured.
4. The damage model has been implemented into ABAQUS through the user-defined subroutine UMAT for FEM analysis.
5. Application of FEA code for a notched specimen (Fig. 1) under static loading: shear deformation (Figs. 2, 3, 4 and 5) and maximum load (Table 1).
6. Application of FEA code for a notched specimen (Fig. 1) under fatigue loading: fracture pattern (Figs. 6 and 7) and fatigue life (Table 2).
7. The effects of mesh size on numerical results have been studied (Table 1).

Table 1. Maximum load (lb)

Integration Type	Numerical Result				Measured Result
	Mesh One	Mesh Two	Mesh Three	Mesh Four	
C3D8R	48.3	43.2	39.8	39.7	
C3D8	38.1	37.7	37.4	37.4	38.4

Table 2. Fatigue life (cycles) at crack length of 0.75 mm (0.5 Hz)

Applied Load	Testing Result	FEA Result
±25 lb	17200	14920
±32 lb	5750	6780

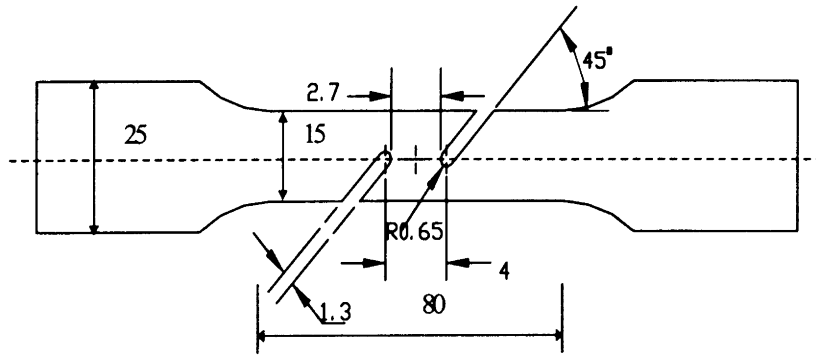

Fig. 1 Specimen configurations (all unit: mm)

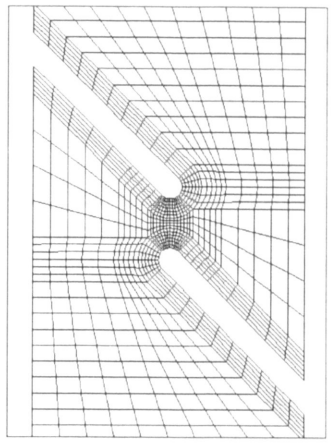

Fig. 2 Undeformed meshes

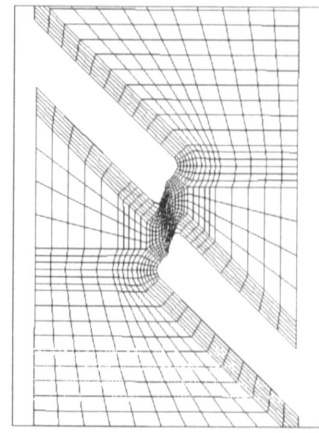

Fig. 3 Deformed meshes under static load

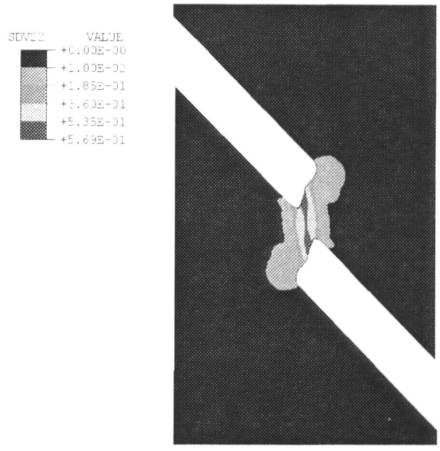

Fig. 4 Contours of overall damage under static load

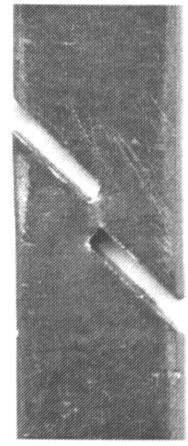

Fig. 5 Test specimen under static load

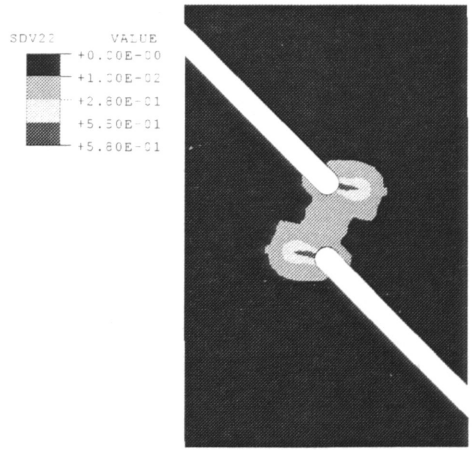

Fig. 6 Contours of overall damage under fatigue load

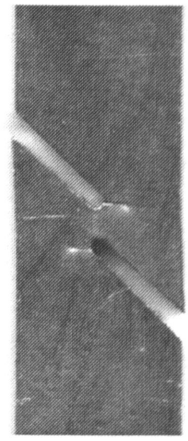

Fig. 7 Test specimen under fatigue load

CONCLUSIONS

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

The model has been implemented into the finite element program ABAQUS (5.6) through the user-defined subroutine UMAT. The fracture patterns of the notched specimen under static and fatigue loading have been calculated using the computer program and the results are found to be identical to those observed experimentally. In addition, the predicted maximum load and the fatigue lives under cyclic loading agree well with their respective measured results.

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 at the 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

Low Energy Impact Damage Tolerance in Automotive Composites

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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PARTNER: Norm Chavka and Susan Ward
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ASSISTANT: B. Sadasivam
Graduate Student Research Assistant

BACKGROUND

Impact induced damages are considered to be one of the limiting factors in the use of composite materials in automotive body and chassis applications. The damages caused by low energy impacts, such as a tool drop, stone impact, or a low velocity collision or bump, may raise concern about the continued and safe use of the damaged part. There may be implications regarding the replacement and repair of the damaged part. There may also be issues related to insurance liability.

OBJECTIVES

The objectives of this study are: (1) to investigate the low energy impact damage tolerance of automotive composites, (2) to understand the damage mechanisms in these composites, and (3) to explore methods to improve their impact damage tolerance.

APPROACH

Several automotive composites are being investigated in this study. Among them are a sheet molding compound (SMC) composite, a structural reaction injection molded (SRIM) composite, a continuous fiber glass fiber mat reinforced polypropylene (PP) composite, a continuous fiber glass fiber reinforced thermoplastic polyester (PET) composite and a short glass fiber reinforced polyamide-6 composite. The initial phase of the study is concentrating on the effect of low energy impact damage on the vibration characteristics of these composites. The next phase of the study will include microscopic and non-destructive inspection of damages caused by low energy impact. The last phase of the study will examine the effect of these damages on the residual mechanical properties of these composites. An analytical model will also be developed to predict the low energy impact damage tolerance of these composites.

RESULTS

Undamaged plate specimens, 100 mm x 100 mm in size, were first modal tested using B&K FFT analyzer and a lightweight impact hammer. For each plate specimen, the first four fundamental frequencies and the corresponding damping factors were determined. Two different methods of specimen supports were explored, namely a thick foam support and a hanging rubber band support. It was observed that fundamental frequencies and

damping factors depend strongly on the support condition. Each plate specimen was impacted roughly at its center with a spherically ended tup in a Dynatup drop weight impact machine. The drop height was varied to produce different input impact energy. The energy absorption pattern and the damage pattern were found to be different for different materials. It was observed that the damage size as well as intensity increase with increasing impact energy.

After impact, each damaged specimen was modal tested to determine the effect of impact damage on the fundamental frequencies as well as damping factors. The fundamental frequencies and damping factors of the damaged plate specimens were not significantly different from those of undamaged plates even though most of the plate specimens contained visible damage.

During modal testing of the damaged plate specimens, it was observed that the center segment of each plate, which contained the damaged area, was showing significantly more modal vibrations than the outer segments that did not contain any impact damage. For this reason, it was decided to separately examine the modal responses of the center segment and the outer segments. Each plate specimen was saw-cut to produce three 33 mm wide narrow plate specimens. These three segments were modal tested separately using the hanging method. It was observed that the damping factor increases with increasing impact energy, whereas, except for the PET composite, all other materials show decreasing natural frequencies with increasing impact energy (Fig. 1a and Fig. 1b).

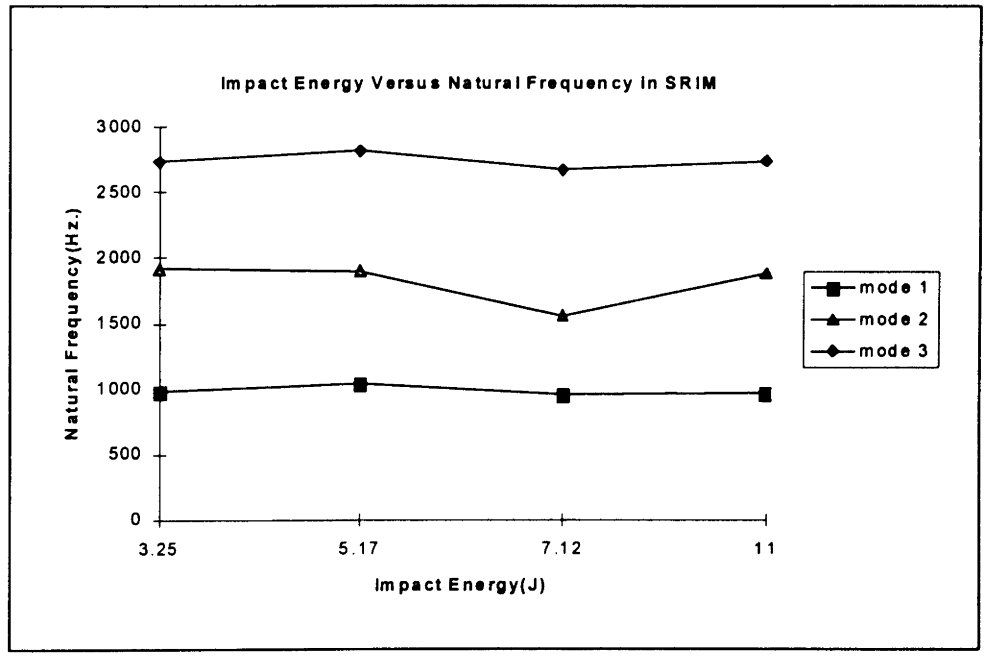

Figure 1a

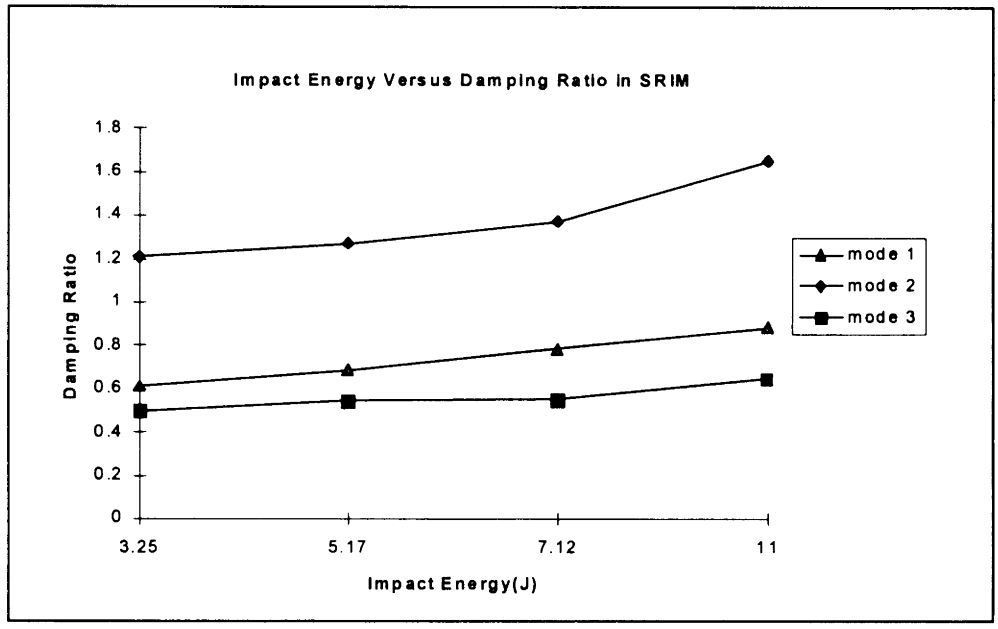

Figure 1b

CONCLUSIONS

The severity of impact damage in automotive composites depends on both the material and the input impact energy. Impact damage tends to influence the local modal properties more than the modal properties of larger structures.

IMPACT

The results of this project will be helpful in discriminating low energy impact damage in various automotive composites. They will also be useful in material selection, since one of the objectives of this research is to compare the impact damage tolerance of composite materials that are being considered for automotive applications. This work will benefit the automotive industry as well as other durable goods industries where such composites are being increasingly used.

One graduate student is engaged in this research in partial fulfillment of his master's thesis. The results of this research will be developed into a case study in ME 587, a graduate-level course titled "Automotive Composites."

ACKNOWLEDGMENT

Cooperation from Dr. Susan Ward of Ford Motor Company in conducting the drop weight impact test at the Ford Scientific Research Laboratory is greatly appreciated. Dr. John Cherng of the Department of Mechanical Engineering has helped in the modal analysis. His help is also greatly appreciated.

REPORT BRIEF

Enhanced Thermal Modeling of the Controlled Atmosphere Brazing Process with Virtual Reality Technology

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

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Climate Control Operations, Visteon

ASSISTANTS: Zhou Youning, Karthik Kumar, Jacob Crossman, Chen Jie

BACKGROUND

A next-generation controlled atmosphere brazing (CAB) furnace is currently being developed [1]. The new furnace is controlled to improve automotive heat exchanger manufacturing. The current CAB process involves assembly of heat exchangers and placing the heat exchangers on the furnace's conveyor belt. The furnace is a long, moon-shaped enclosure where the walls are heated to brazing temperatures by electrical resistance heating. The enclosure is insulated on the outside and filled with nitrogen, an inert gas. The heat transfer process, the heat exchanger temperature history, plays an important part in the quality of the braze. Since the temperature history of the heat exchanger is difficult to know, quality of the braze is determined by physical inspection.

A heat transfer model of the process is needed to predict the temperature history of the heat exchanger. A diagnostic tool is needed to inform the furnace operator of the real-time heat exchanger temperature. A full-scale, interactive, graphical simulation of the process can provide the operator with needed information to control the process with improvement in heat exchanger braze quality. Current graphical representation techniques are slow and not real-time.

Virtual reality (VR) technology can provide real-time graphics. VR is described as the science of integrating people with information. It consists of three-dimensional, interactive, computer-generated environments. These environments can be models of real or imaginary worlds. In virtual engineering simulation, conceptualization of complex or abstract systems is made possible by representing their components such that they can function dynamically according to the laws of physics and can be interacted with through control and monitoring devices. In a virtual simulated engineering environment, the use is entirely inside the virtual environment and influences it from within. Therefore, virtual simulation is a promising technology for studying the CAB process.

OBJECTIVES

The objectives of this first phase of the project were to:

- Develop an engineering heat transfer model of a heat exchanger in a controlled atmosphere brazing furnace

- Compare model results with current data
- Develop a proof-of-concept "virtual" CAB furnace that allows minimal capability for the user to "walk" through, observe, and interact with the heat exchanger manufacturing process

APPROACH

The approach taken to develop the VR-CAB model was:

- Development of a virtual reality model that simulates the dynamic/visual aspects of the furnace enclosure, conveyor belt, and heat exchanger.
- In parallel to this effort was the comparison of the heat transfer model results with recorded temperature measurements of current radiator production.
- After VR modeling was completed, the final step was integration of the existing CAB thermal model [2,3] with the virtual reality framework.

RESULTS

The objectives of this phase of the project were accomplished. The VR framework was successfully developed on an SGI workstation in the Computer Vision and Intelligent Systems Lab (CVIS) at the University of Michigan-Dearborn. The VR framework was developed with the virtual simulation package WorldToolKit (WTK) by Sense8. The software uses the C++ programming language. Interaction between the user and the simulation is through screen terminal visualization, keyboard, and mouse input. The user is able to passively observe the heat exchanger traversing the furnace. The user can move in and out of the furnace, control conveyor belt speed, and set furnace wall and heat exchanger temperatures.

The thermal heat transfer model was compared against existing recorded temperatures measured from a production radiator that was brazed in a production CAB furnace. From preliminary comparisons, general trends were predicted [4].

The heat transfer simulation and VR simulation were integrated. The thermal model was written in the FORTRAN programming language and was modified as a subroutine that was called by the VR program. The VR program called the subroutine at the VR simulation's frame-rate. Heat exchanger temperatures were passed to the VR simulation to update the temperature visualization on the terminal screen. A color scheme was developed to provide visual thermal sensation [5].

CONCLUSIONS

A framework has been developed for the heat transfer process in a VR-CAB furnace and has shown promising capabilities as a predictive and diagnostic tool. In continuing this project, effort is needed to improve thermal model accuracy and flexibility. The virtual simulation needs refinement of its dynamics and color scheme to provide improved visual thermal sensations.

IMPACT

This project's impact on education has been to provide a topic for a master's student in mechanical engineering.

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REPORT BRIEF

Performance of an Automotive Helical Heat Exchanger Design

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Eric B. Ratts
Department of Mechanical Engineering

PARTNER: Climate Control Operations, Visteon

ASSISTANTS: Several mechanical engineering undergraduate students

BACKGROUND

Manufacturing current heat exchangers requires a series of manufacturing processes. Several tubes, fins, headers, and supports must be assembled into a relatively complex arrangement. It is important that they be put together with small tolerances to ensure high-quality brazed joints. If the number of parts to be assembled were less, it would reduce the number of joints and reduce the number of rejected heat exchangers. It also might reduce the number of manufacturing processes and improve production efficiency, which would be beneficial to industry.

OBJECTIVES

Investigate a helical heat exchanger design for an automotive evaporator to meet current heat loads and reduce the complexity of manufacturing.

APPROACH

This problem was posed to several groups of mechanical engineering students as their senior design project. Some of the designs had a similar shape in that they included a round tube and a helical geometry. This shape was chosen as the method of meeting the objective. A heat exchanger was designed incorporating the round tube and helical geometry, as shown in Figure 1.

A steady-state, resistance-analogy model was developed making several simplified assumptions. For example, two-phase flow was modeled as homogeneous. Characterization of two-phase, helical-flow heat transfer and pressure drop was based on single-phase flow correlations using mass-averaged properties.

The method of optimization most commonly used in designing heat exchangers comes from experience. Experienced designers understand the trade-off between pressure-drop losses and heat-transfer losses. The optimization of this heat exchanger was based on a quantitative thermodynamic analysis, which is not often used because of the difficult concept of entropy. Through an entropy generation minimization approach, the heat exchanger was optimized based on several design constraints.

RESULTS

It was demonstrated that the heat exchanger design can be optimized based on entropy generation minimization. Conclusions were made and quantified based on the thermodynamic analysis. Figure 2 shows the result of entropy generation minimization. It graphically

shows the tradeoff of heat-transfer losses and pressure-drop losses. An increase in the loss is shown by an increase in entropy generation. The figure identifies an optimal tube diameter for the helical design shown in Figure 1.

First, due to the similar unit geometry, the heat transfer surface area required for the refrigeration capacity is approximately the same as current designs. Requiring the same heat transfer surface area involves headering several tubes together, which unfortunately increases the number of parts and the number of brazed joints.

Second, the entropy generation analysis was able to quantify the heat-transfer losses and pressure-drop losses individually. It was identified and quantified in terms of entropy generation that the heat transfer coefficient on the air side is significantly lower. The low heat transfer coefficient requires large heat transfer surface area to reduce entropy generation, but increasing surface area tends to increase pressure-drop entropy generation. The poor heat transfer performance on the air side has been identified as a controlling factor in the design.

Third, due to manufacturing difficulties in constructing small fins to create small air-side hydraulic diameters and small radius of curvatures for the helix, a new evaporator design was identified that integrates the current evaporator case and air ducting.

CONCLUSIONS

Advantages and disadvantages of the helical-geometry evaporator design have been identified and warrant further investigation. It does have exciting possibilities in terms of manufacturing, as previously proposed, as well as new packaging opportunities for automotive air conditioning systems. Based on this work it has been identified that two-phase, empirical heat transfer and pressure-drop correlations are needed for the helical flow.

IMPACT

This project's impact on education has been to provide a topic for undergraduate mechanical engineering students fulfilling their design credit (ME 425). It has also provided a master's student a topic for his thesis.

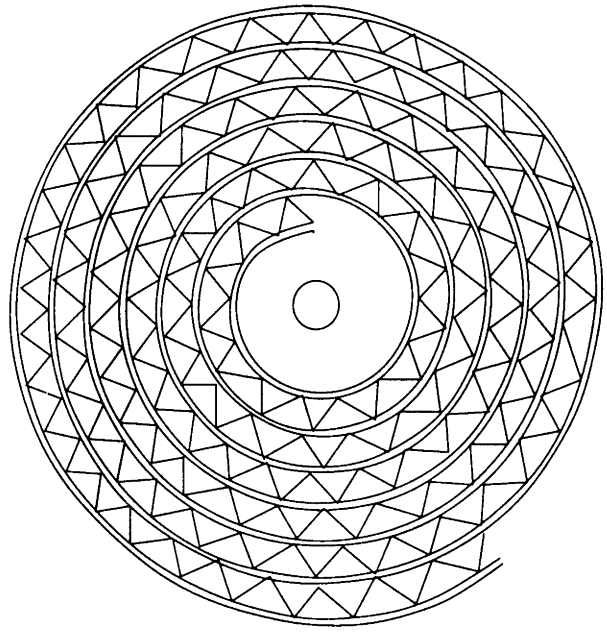

Figure 1: Schematic of Helical Heat Exchanger Geometry

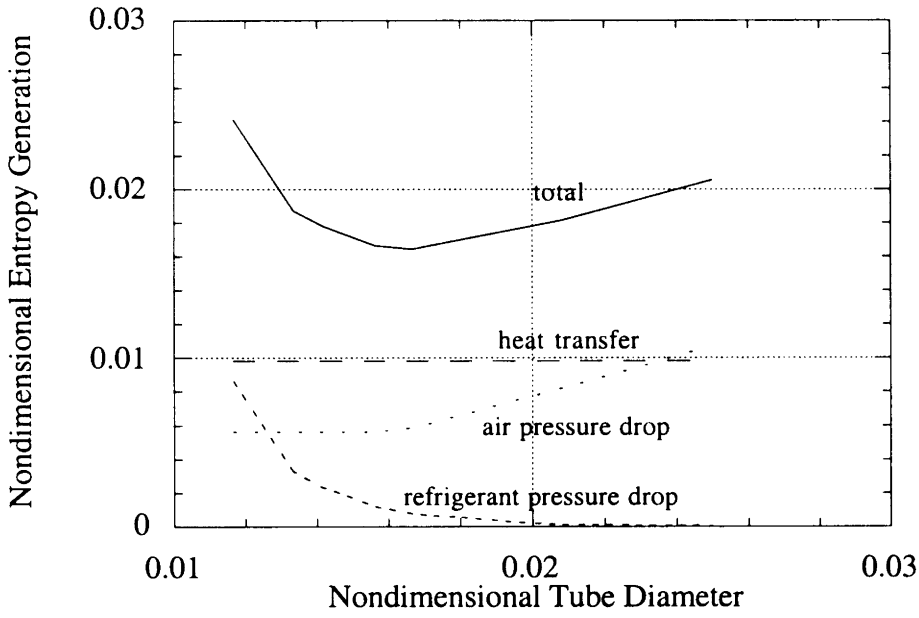

Figure 2: Optimal Helical Heat Exchanger Geometry
Based on Entropy Generation Minimization

REPORT BRIEF

Performance Analysis of Catalytic Converters

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Tariq Shamim and Subrata Sengupta
Department of Mechanical Engineering

PARTNERS: Andrew A. Adamczyk and Seha Son
Ford Motor Company

ASSISTANT: Huixian Shen
Research Assistant

BACKGROUND

Meeting increasingly stringent emission requirements is a very important challenge faced by the U.S. auto industry. This challenge makes emission control a major thrust area in engine research. As indicated by the recent Kyoto Protocol, the emphasis on emission control will be continued in the next century. Emissions from engines are major sources of urban air pollution. The engine exhaust gases contain oxides of nitrogen (NO_x), carbon monoxide (CO), and partially burned or unburned hydrocarbons (HC). These pollutants can be removed from the exhaust gases by employing catalytic converters.

Catalytic converters have been used in automobiles for several years and various types of them are available. Their designs, however, need to be improved to obtain better conversion efficiency in order to meet the new emission requirements. An improvement of design requires better fundamental understanding of complex processes taking place in converters involving fluid flow, heat and mass transfer, and chemical reactions. The design improvement also requires, in addition to experimental testing of converter models (which is expensive), an ability to numerically simulate the models and predict the converters' performance.

OBJECTIVES

The objective of this work is to develop a robust, efficient, and accurate computational model to analyze and improve the performance of catalytic converters.

APPROACH

The governing equations are obtained by considering the fluid flow, heat and mass transfer, and chemical reactions. The resulting equations form a set of transient, non-linear and stiff partial differential equations. The stiffness is due to different time scales in the problem owing to different reaction rates of various species involved in a catalytic converter. Besides stiffness, the other challenge in numerical solution of the governing equations is to simulate the varying load conditions under different operating conditions of a vehicle.

The physical processes in a converter can be fully described by using a transient two-dimensional model. However, the long execution time for such a model will make it less useful. Since the main focus of attention in this study is the catalytic converter's efficiency, which can be estimated with a good accuracy by employing a transient one-dimensional

model, only a single spatial dimension is considered in the present work. The study may be divided into three phases:

- Phase I: Development of a steady state one-dimensional code with uniform flow
- Phase II: Development of a transient one-dimensional code with uniform flow
- Phase III: Development of a transient one-dimensional code with flow variation

RESULTS

The first phase of this study, which deals with the development of a steady state code, has been completed. The code is used to investigate the effect of the following parameters on the converter's efficiency:

Effect of Catalyst Length

Hydrocarbon conversion efficiency increases with the increase of catalyst length (Figure 1). However, the change in length does not have much impact on the conversion efficiencies of CO and NO. Results show that the change in length is more important for short converters and it becomes gradually less important for long converters. Keeping other dimensions constant, increasing the length of long converters may even have an adverse effect on the conversion efficiency since it will take longer time for the substrate temperature to reach beyond light-off temperature during a cold start period. Furthermore, a long catalyst will also increase the cost of converters.

Effect of Monolith Cell Density

The effect of increasing the cell density is similar to that of the catalyst length (Figure 2). The higher value of the cell density is limited by the consideration of the corresponding increase of the back pressure (engine exhaust pipe pressure). If the back pressure is too high, it will deteriorate aspiration of the engine and thereby the engine performance.

Effect of Wall Thickness

Figure 3 shows that the thinner the monolith wall thickness, the better is the HC conversion efficiency. Thin wall thickness is also desirable since it decreases the substrate thermal capacity. This results in a fast heating of the catalyst during the cold start and thereby a decrease in cold start emissions.

Effect of Cross Sectional Area

Large catalyst cross sectional area slows down the flow rate of the exhaust gases. This causes the catalyst reaction to take place in a relatively long time, and thus increases the conversion efficiency (Figure 4). In the present model, the effect of non-uniform flow in the catalyst is not considered. Increasing the cross sectional area usually leads to a more non-uniform flow and thus may result in the reduction of the conversion efficiency.

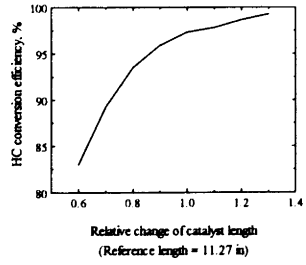

Figure 1. Effect of catalyst length

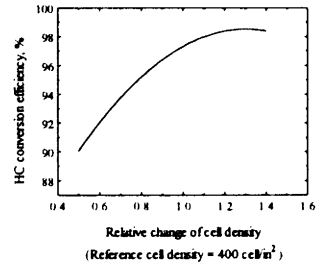

Figure 2. Effect of cell density

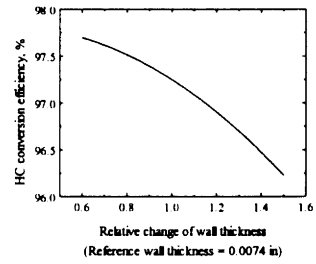

Figure 3. Effect of wall thickness

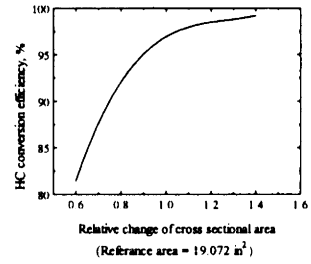

Figure 4. Effect of cell x-sectional area

IMPACT

This project will provide research experience to students at both undergraduate and graduate levels. It will produce a few topics for an undergraduate senior design course (ME 425). Four senior students are currently working, under the supervision of the first author, on related projects for their senior design course (ME 425) and directed study (ME 491). The work will also be useful for the graduate level course on internal combustion engines (ME 597) which deals with the topics of pollutant formation and emission in engines. Furthermore, the work will result in recommendations to improve the catalytic converter designs. Such improved designs will assist the auto industry to meet the stricter vehicle emission standards.

REPORT BRIEF

The Effect of Time Dependent Partial Premixing In Radiating Flamelets

June 24, 1998

CENTER FOR ENGINEERING EDUCATION AND PRACTICE
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY OF MICHIGAN-DEARBORN

AUTHOR: Tariq Shamim
Department of Mechanical Engineering

PARTNER: Currently being sought

BACKGROUND

Deteriorating environmental conditions caused by pollutant emissions is a matter of greater concern to all nations of the world. Due to the hazardous effects of pollutants, increasingly stringent emission regulations are being imposed, which puts a great emphasis on the development of emission control techniques. Natural gas burners, which are used in most manufacturing plants, are major contributors of urban pollution. The natural gas is preferred as a fuel due to its cost effectiveness. However, these burners emit oxides of Nitrogen (NO_x) which in the presence of sunlight and hydrocarbon form ozone in the lower atmosphere. Ozone is a key component of smog and contributes to a variety of health problems. NO_x also contributes to the global warming through its breakdown form, Nitrous Oxide, which is a greenhouse gas.

Since there are millions of burners in the manufacturing sector, improvement of their designs to reduce pollutant emission is a very critical issue. The importance of this issue has prompted several studies in this area. Some recent studies [1-3] have shown that NO_x emission may be reduced by partial premixing (mixing of a small quantity of oxidizer on the fuel side or a small quantity of fuel on the oxidizer side of the diffusion flame, which results in a double flame configuration, as shown in Figure 1). This finding has led to a growing interest in partially premixed flames. However, there still is a lack of clear understanding of the basic flame structure and pollutant emission characteristics of these flames.

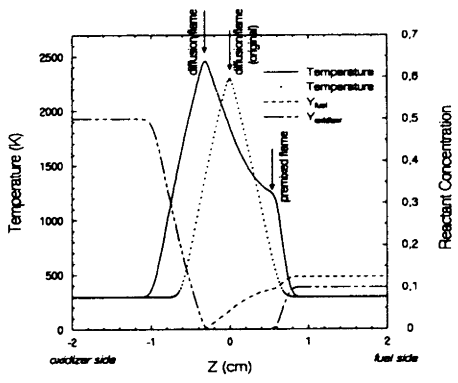

Figure 1. Temperature and reactant concentration profiles of a partially premixed flame

The study of time dependent partial premixing is also important on a fundamental level. In most turbulent jet diffusion flames, there is a small quantity of oxidizer mixed with the fuel prior to ignition. In such flames, due to the presence of large and micro scale eddies, the degree of premixing is very time dependent. Hence, an investigation of the effects of the time dependent partial premixing will aid in better understanding and modeling of turbulent diffusion flames.

OBJECTIVES

The objective of this pioneer work in turbulent combustion modeling is to investigate the effect of time dependent partial premixing on the pollutant formation and to subsequently suggest a course of action to improve industrial burner designs with less pollutant emissions.

APPROACH

In this study, we use a novel idea which employs time dependent partial premixing to control NO_x emission in diffusion flames. The governing equations are developed based on the conservation of mass, momentum and energy. The assumption of axisymmetry together with similarity transformations reduce the governing equations into single spatial dimension. The resulting governing equations form a set of transient, non linear and stiff partial differential equations. The stiffness of equations (which is due to the presence of several time scales, as a result of different reaction rates of various species) poses a challenge in achieving efficient converging solutions. In the present work, the governing equations are solved by employing *numerical method of lines* (NMOL).

The simulations are carried out by considering a steady state partially premixed flame that is suddenly subjected to variations in partial premixing. Two types of imposed changes (sinusoidal and step change) are considered. The imposed changes greatly affect the diffusion flame properties. Of main interest in this investigation are the effects of these time dependent changes on flame temperature, its structure, pollutant formation and destruction characteristics.

In the first phase of this study, a simplified chemistry model consisting of a single-step overall reaction is used. The use of simple chemistry allows us to concentrate more on understanding the effect of time dependent partial premixing on the flame temperature and its structure—the characteristics which have significant influence on flame's pollutant formation mechanism.

In the second phase of the work, the effect of chemistry will be explored by modifying the chemical reaction scheme. A reduced mechanism consisting of four-step chemistry will be included. This will help capture the effect of partial premixing on few more species. The results are expected to provide a better estimate of the effect of partial premixing on pollutant formation. The conclusion of the second phase will lead to the exciting third phase of the proposed work. During the third phase, a very detailed chemical reaction scheme will be included, and the effect of partial premixing on minor species will be investigated.

RESULTS

The first phase of this work, which uses a simplified chemistry model, has been completed. The flame response to both sinusoidal and step changes in partial premixing are investigated. The effects of the following parameters are studied:

- Effect of Level of Premixing
- Effect of Fluctuation Frequency

- Effect of Strain Rate
- Effect of Lewis Number

CONCLUSIONS

The results lead to the following conclusions:

- The flame responds sinusoidally with a phase shift to the sinusoidal imposed fluctuations in partial premixing. The response is nearly symmetric with respect to its mean steady value. However, the amplitude of the response increases with an increase in the degree of premixing.
- At lower frequency, the flame response is quasi steady. As the imposed frequency is increased, the flame response decreases and its phase lag increases. Eventually the flame becomes insensitive to the imposed fluctuations.
- The flame response increases with an increase in the strain rate. This increase is due to an enhanced role of convection and the closer proximity of the premixed flame to the diffusion flame.
- The ratio of frequency over twice the strain rate ($f/2\varepsilon$) may be used to predict the flame response to the imposed partial premixing fluctuations. The flame response is quasi steady for $f/2\varepsilon \leq 0.1$ and its amplitude decreases exponentially for $0.1 \leq f/2\varepsilon \leq 1$, beyond which the flame becomes insensitive to fluctuations. Hence the transient effects must be considered in the flamelet modeling for the critical range $0.1 \leq f/2\varepsilon \leq 1$.
- The effect of fluctuations is greater on flames with Lewis numbers greater than unity. This is due to weakening of the diffusion flame at high Lewis numbers so that it becomes more susceptible to fluctuations in partial premixing.
- The flame responds to a step change with a time delay. With an increase in the step size (degree of premixing), the response increases.
- For a step change, the initial time delay in the flame response and the time to reach the steady state depend on the strain rate and are independent of the degree of premixing.

IMPACT

By identifying the regime where transient effects are important, this work makes a fundamental contribution in turbulent combustion modeling. The work will also provide research experience to students at both undergraduate and graduate levels (ME 491 and ME 600). The work may be useful for case studies in the graduate course on combustion (ME 532). Furthermore, the work will lead to guidelines to improve industrial burner designs with reduced pollutant emissions.

ACKNOWLEDGMENT

Partial financial support from the Office of Research and Sponsored Programs of the University of Michigan-Dearborn is greatly appreciated.

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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

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