On Dreams and Timing

Yoram Koren

James J. Duderstadt Distinguished University Professor of Manufacturing
College of Engineering, The University of Michigan, Ann Arbor

"The world of manufacturing has changed dramatically in the past thirty years and Professor Koren has been in the forefront of that change."

— U-M Provost Phil Hanlon, March 27, 2012

Engineering is what enables you to realize your DREAMS about innovations that can benefit people, society and the economy. But for dreams to be realized they must be based on actual engineering foundations and pursued at the appropriate time. Some call this luck. We call it **timing**.

A good example is the establishment, in 1996, of the University of Michigan Engineering Research Center for Reconfigurable Manufacturing Systems (ERC–RMS), sponsored by the National Science Foundation. The mandate of NSF-supported ERCs is to explore a field relevant to industry success. Hence, industrial support is an important factor in establishing a prestigious center.

NSF regards our ERC–RMS as one of its most successful centers, partly due to the generous financial support received from industry, more than any other NSF-sponsored ERC. Most of this industrial funding came from the Big-Three auto makers. From 1996 to 2007 these companies provided us generous financial support. But just suppose we had tried to found such a center in 2008, when the auto industry was in crisis. Even if you do exactly the same thing, it is circumstances that determine whether you succeed or fail. TIMING IS EVERYTHING.

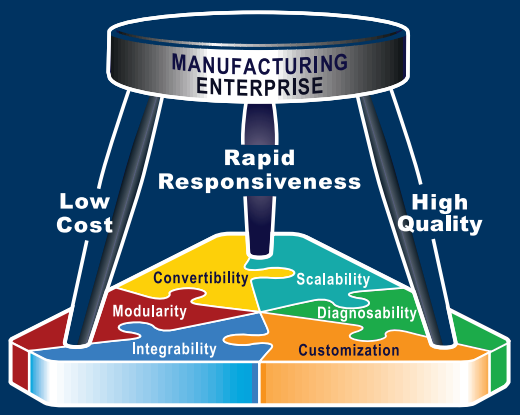
Koren's Impact—a Profile

4	Original books, translations into Japanese, French and Chinese
14	Patents
300	Published Papers
16,000	Citations to Koren's papers (per Google Scholar)
56	*h*–index
50	Graduate students
$50M	Received and managed in grants and contracts

- Professor Koren established the first NSF-sponsored Engineering Research Center (ERC–RMS) at the University of Michigan—a major milestone in the College 150-year history
- Member of the National Academy of Engineering
- Distinguished University Professor
- Fellow of ASME, SME, IEEE, and CIRP

Reconfigurable Manufacturing Systems

Professor Koren is credited with conceiving the RMS paradigm and creating a new research discipline-RMS- with practical implementations. In the early 1990's Professor Koren predicted that globalization would become a major factor in industrial competition, making the ability to respond rapidly to changing markets a vital goal for industry. Hence, Koren added Rapid Responsiveness to the traditional goals of Low Cost and High Quality products. In 1995 he submitted to NSF a proposal to establish an Engineering Research Center for Reconfigurable Manufacturing Systems that are designed to be responsive to market changes.



A 21st Century manufacturing enterprise must be based on High Product Quality, Low Cost, and Rapid Responsiveness that are grounded on six RMS characteristics, first defined by Yoram Koren in 1995.

The NSF-sponsored ERC for Reconfigurable Manufacturing Systems was launched on **August 1, 1996**. It was the first NSF-sponsored ERC at the University of Michigan. The RMS science base was developed according to six RMS characteristics defined as essential for achieving the goals of responsiveness, cost and quality.

A **responsive** manufacturing system must be designed for **volume scalability** that allows the production capacity to be rapidly **scalable** to produce more products exactly when the market needs them. The system must be easily **convertible** from one product to another that customers like more.

A system with in-line **diagnosibility** facilitates rapid ramp-up (which enhances responsiveness and reduces cost), and produces good quality products. To achieve in-line diagnosibility, we developed a method, software, and hardware—the RIM (reconfigurable inspection machine) that can detect, for example, surface pores on engine blocks, as explained on the next page.

"The ERC–RMS has worked with its partners to move research and innovations from the testbeds to adoption by industry."

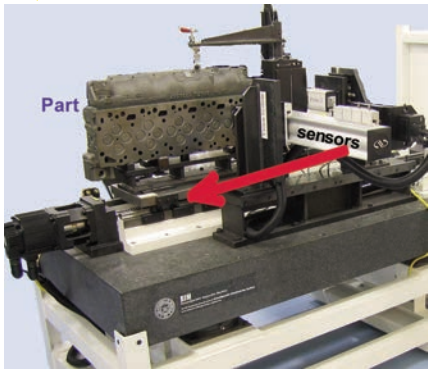
—the NSF final report (May, 2007)

Old Inspection Method

Visual inspection by an operator. Hard to find pores of smaller than 1mm

RIM integrated into GM engine production line (2006) Defects are detected by the RIM technology at the line speed, and displayed to the operator in real time

New Inspection Method



Koren invented and patented the Reconfigurable Inspection Machine (RIM)

High-resolution images of the engine block surface are acquired by the RIM at the line speed using a computerized vision system. The images are then analyzed to detect and measure pores (small pits < 1mm on the surface, resulting from casting). In 2006 General Motors installed our in-line surface porosity inspection system at its Flint, Michigan engine plant. The inspection system was integrated into the production line, with a conveyor moving all engine blocks through this station. Using our technology, GM prevents defective parts from reaching customers. Before the RIM was installed, an operator visually inspected each block at the line rate (20 seconds/engine block).

Three major U.S. patents, all invented by Koren, define the RMS paradigm: The whole reconfigurable system, the in-line inspection machine and method, and the Reconfigurable Machine Tool (RMT). At the International Manufacturing Technology Show (IMTS) in Chicago in 2002, the ERC–RMS introduced the world's first full-scale Reconfigurable Machine Tool based on Koren's 1999 patent and his conceptual design.

Koren is the co-inventor (with S. Seagall) of the Cylinder-Bore Inspection Machine that can measure pore defects inside deep holes, such as those of engine pistons.

Dean David Munson discusses the Cylinder Bore Inspection Machine with Dr. Reuven Katz

The Reconfigurable Machine Tool Koren's patent #5,943,750 (1999)

In 1999, Koren introduced at the CIRP General Assembly the main concepts of RMS. Today this keynote paper has 1,300 citations. In addition to creating reconfigurable manufacturing and defining its core characteristics and principles, Koren also holds 7 US patents on reconfiguration system and machine technologies. Under Koren's leadership the ERC built the best manufacturing research infrastructure in the U.S. (photo below).

"The physical manufacturing infrastructure developed by the ERC–RMS is unique in the US. No other university has space and experimental equipment like it, and it is one of the best in the world."

—the NSF final report evaluating 11-year activity of the ERC–RMS (2007)

ERC Reviews By NSF From 1997 to 2007, a team of experts from academia and industry made annual onsite visits to the ERC. The final NSF site visit was in 2007, summarizing 11 years of NSF financial support. The report states:

"There is a strong evidence of the effectiveness of both the vision of the Center Director and the ability of the director to execute the vision."

—the NSF final report evaluating 11-year activity of the ERC–RMS (2007)

Twenty-five manufacturing firms were contributing members of the ERC–RMS (among them Chrysler, Ford, GM, Cummins, Caterpillar, Boeing, control vendors and machine builders). The Center received very generous financial support from industry from 1996 through December 2010. The Center operated until 2013.

During the Center's lifetime it received $47 million from government and industry sources. Many of the tools it created are used today in manufacturing plants around the world. Koren is widely considered as the **Father of Reconfigurable Manufacturing Systems**—an innovation that transforms factory floors, enabling industry to react quickly and intelligently to changing market demands or unacceptable product quality issues.

"How many of us have the opportunity of transforming a whole field and see the results in our lifetime ?"

—Steve Director, CoE Dean, in a speech to the NSF site visit team, May 2004

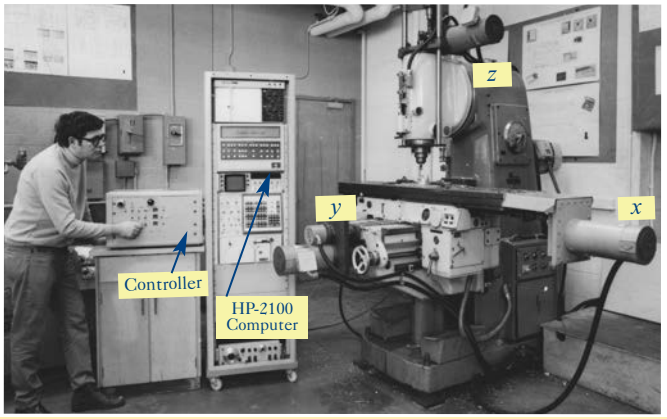
Manufacturing Automation

Professor Koren's pioneering inspirational research laid the scientific basis for precise computer control of machines. Since the late 1960's Koren has developed innovative control methods for NC machine tools aimed at enhancing their precision and increasing their productivity. In a series of 20 papers published between 1970 and 1982 Koren laid the intellectual foundations for precise control of CNC (computer numerically controlled) machines and large manufacturing systems. CNC machine tools form the backbone of producing high-precision parts, such as automobile engines and transmissions, turbine blades for jet engines, and various aluminum parts for the aerospace industry. Before Koren's pioneering work in the 1970's, numerical control of machine tools was more an empirical craft than a science. His research on the synthesis and analysis of CNC systems established a scientific approach to the control of machine tools and manufacturing systems. Many of today's CNC systems in industry make use of the tools and software Koren developed in the course of his extensive research.

Adaptive Control

In 1973, long before computers were commonly used in industrial applications, Koren invented the **world's first** computerized real-time adaptive controller (AC) for a milling machine. This adaptive control concept involves letting the machine controller calculate the most productive speed during processing. This pioneering technology laid the foundation for an effective means of controlling processes – a technology still widely used in industry. Later, Koren applied the AC algorithm to turning, grinding, ECG, and other processes.

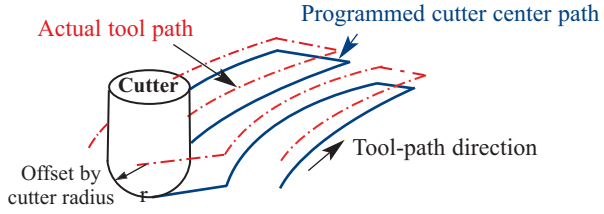
Koren demonstrates the CNC-AC Milling Machine that he designed
McMaster University, Canada, 1973



The CNC-AC control computer was HP-2100 — a 16-bit computer with a 4K memory, and cycle time 1μs. The computer runs the AC program, the interpolator, and the controllers for three axes, and measures in real-time signals from a force sensor mounted on the spindle

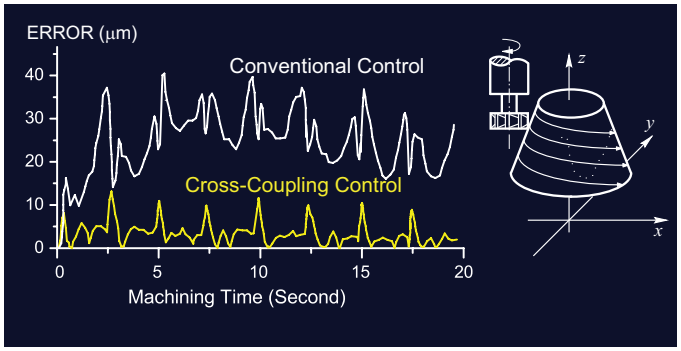
CNC Interpolators

CNC interpolators coordinate the motions of the separately-driven perpendicular machine axes, such that the tool cuts precisely non-linear curves. To cut a circle, for example, the interpolator generates X and Y velocity commands that are proportional to sin(wt) and cos(wt). In 1976 Koren published the **first scientific paper** about CNC interpolator algorithms (*IEEE Trans. on Computers*). Later, Koren and his students introduced interpolation algorithms that generate 3-D complex surfaces, including cutter radius compensation and path segmentation (see sketch).

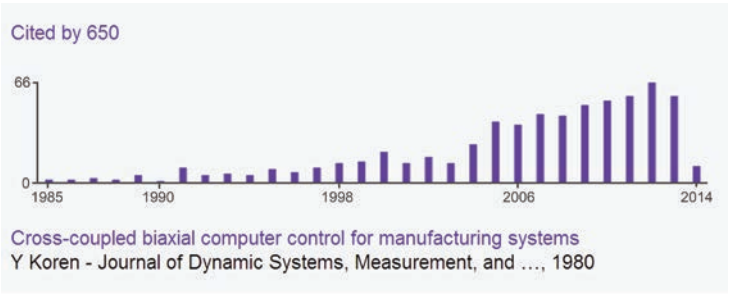


Cross-Coupled Control

In 1980, Koren invented the cross-coupled control (CCC) method. The CCC enhances the precision of CNC systems and thereby produces higher-precision parts that consequently contribute to generating better products. As seen in the experimental result below, applying the CCC algorithm enhanced the precision from 40μm to 10 μm. Moreover, the CCC algorithm enhances precision not through additional investment in hardware, but rather solely by coordinating motion by means of software. Machine builders have been implementing this method since the 1980's.



Experimental results of CCC and conventional control when cutting a cone



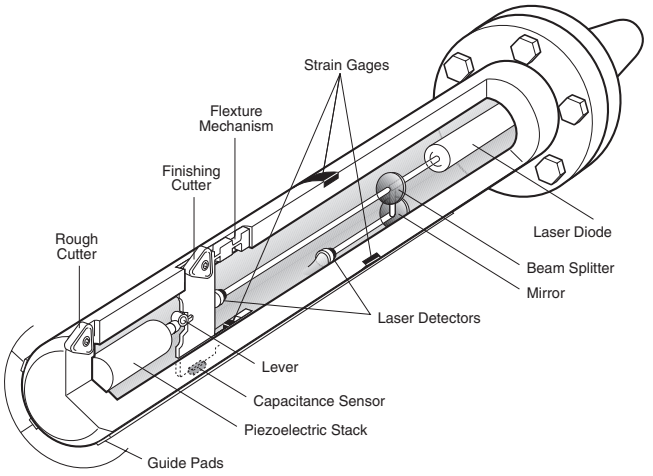
Google Scholar citation graph of the CCC paper (March, 2014)

As seen in the graph above, for the first 20 years after its publication in 1980, Koren's CCC paper did not receive much attention. From 2000 on, the paper became popular. The CCC method has served as the basis for Ph.D. dissertations at numerous universities. Its concepts have been applied not only to machine control, but also to coordinating the motion of two robots assembling a product, two flying helicopters, and in enhancing communications systems.

Smart Tool - In-Process Compensation

In a $1-million project awarded to Prof. Koren by NIST in 1994, he and his team built a Smart Tool for a boring station. The station had to machine precise (2μm), long holes (60 cm) in engine blocks, when it could control only the Z-motion to maintain precision. The Smart Tool had to perform X and Y compensations in real-time while rotating at 5,000 rpm.

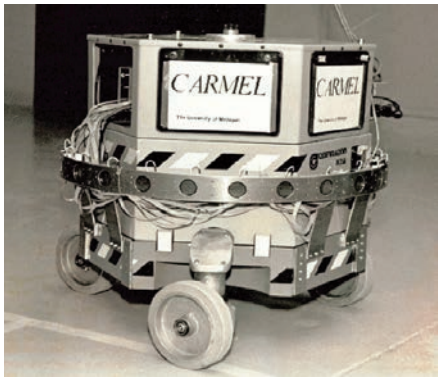
The Smart Tool on-line compensation mechanism relied on tool-tip piezoelectric actuator. X-Y errors were monitored by an internal cutting force sensor, and two internal laser beams. The Smart Tool contained a computer to coordinate the tool X-Y axes with the machine Z-axis using a cross-coupled controller. The machine was built and operated successfully.



Robotics

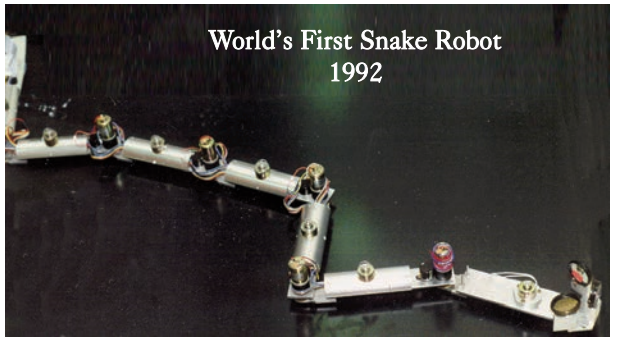
Koren's hallmark in robotics is a rich body of highly cited scholarly papers in autonomous mobile robotics. He and his former student Johann Borenstein invented autonomous motion algorithms for robots moving towards a known target in unstructured environments crowded with many objects at unknown locations. The challenge was to represent these uncertain objects, reason with incomplete domain knowledge obtained from 24 ultrasonic sensors surrounding the mobile robot, CARMEL, and make motion decisions while the robot is moving at high speed (0.8m/s) (watch on YouTube: CARMEL on CNN.

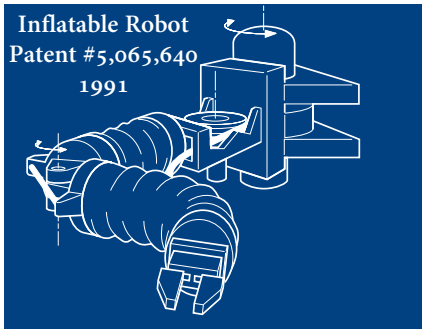
The link: http://www.youtube.com/watch?v=oQ-1pnm6MPk)



July 1988: Koren and CARMEL on CNN's nationally televised program "Ahead"

In 1991, Koren received an NSF grant to develop a snake robot. He and his graduate student, Yansong Shan, built the world's first mechanical snake robot that moves without wheels. Outfitted with a camera, it was designed to worm into crevices to aid in search for victims. This pioneering work inspired research on snake robots at many universities worldwide.





Koren built and patented an inflatable robot invention (supported by NASA, 1991). The links of the robot are made of thin film material and are inflatable. The inflatable arm linkages were intended for deployment in hostile and confined spaces. The inflatable robot can achieve the required load-bearing capacity and rigidity by selection of appropriate size and pressure. This robot could prove useful for surveillance and resource operation or in areas difficult to access in buildings.

Rehabilitation Robotics

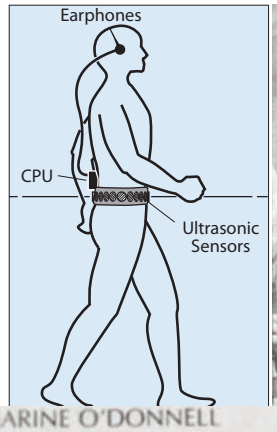
"CARMEL garnered the attention of CNN and other media, and increased the public interest in rehabilitation robotics."

—Provost Phil Hanlon, March 27, 2012

Since the early 1980's Koren developed innovative robotic technology to assist persons with disabilities and contribute to their sense of well-being. In 1983 Koren applied his knowledge in adaptive control to develop together with his Ph.D. student Aaron Bar a computerized adaptive knee prosthesis. In 1984 Koren and his student Johann Borenstein developed a mobile Nursing Robot equipped with robotic arm to assist bedridden persons. The Nursing Robot and the CARMEL navigation method laid the foundations for the invention of the NavChair—an adaptive wheelchair. The operation is based on a shared-control algorithm, with seamless transfer between two modes: in cluttered environments the computer controls the NavChair; in obstacle-free space the user controls it.

Based on the CARMEL method, Koren, Borenstein and their student Shraga Shoval developed the NavBelt–a user-worn obstacle avoidance device that guides blind users around obstacles by means of audio signals.

Nursing Robot, 1984
"Bring me a magazine"



The NavBelt, 1993
Guides blind around obstacles

By CATHARINE O'DONNELL
NEWS SPECIAL WRITER

Yoram Koren and colleagues in his mechanical engineering lab at the University of Michigan have invented a belt that takes blind people where they want to go and a motor-driven snake that takes a camera into places where no one wants to go.

Koren, the Paul G. Goebel Professor of Engineering, got his idea for the snake after the San Francisco earthquake of 1990. He saw television pictures of an eight-inch concrete crack in Highway 80. People were thought trapped underneath. "I realized a robotic device with a camera would be able to get in there and see what was going on," says Koren.

The NavChair, 1993

Three Ideas That Could Change the World (for the better)

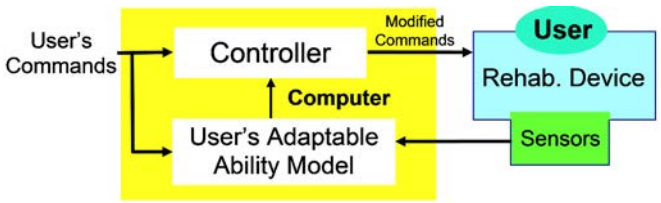
> *"But Koren still has DREAMS that have not been realized. He still has big ideas."*
>
> —Ncole Casal Moore, UM Record, March 19, 2012

1. **Adaptive assistive devices: for rehabilitation, for older adults, and for the people with disabilities**
2. **Open-architecture personalized products—an engineering-business strategy to create local jobs**
3. **Technology for Peace—grassroots cooperation among international students to creates peace**

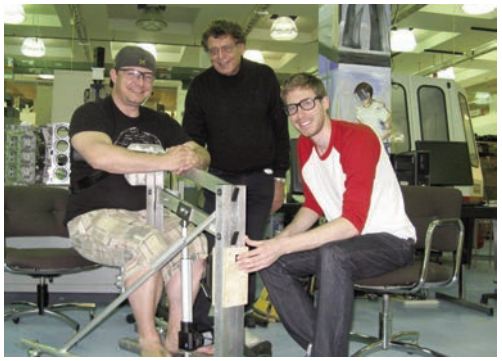
1. Adaptive Assistive Devices

The NavChair control is based on using the wheelchair's sensor information and user's ability to alter the wheelchair user's commands by applying the adaptive control algorithms that Koren applied to control machines. Combining control and modeling theory with human behavioral science will create a new research discipline—Adaptive Assistive Devices—that will make the devices more adapted to their individual user's needs and ability.

The block diagram depicts the concept. Using sensors (e.g., heartbeat, arm-reach) as well as constraints given by the care-givers, the controller automatically acquires knowledge about the user's ability and constraints, and changes the user's commands according to the acquired knowledge, so the user is safe.



A self-elevating wheelchair, Koren's Project, 2009



Koren with his students, Matt and Nathan, built an innovative Sit-to-Stand Assistive device (2011)

Hand-operated exercise bicycle (2012)

2. Open-Architecture Personalized Products

"In another **DREAM** *Koren envisions reconfigurable car interiors. One person might choose a dog basket instead of a passenger seat. Another might prefer a refrigerator instead of a back seat."*

—Nicole Casal Moore, UM Record, March 19, 2012

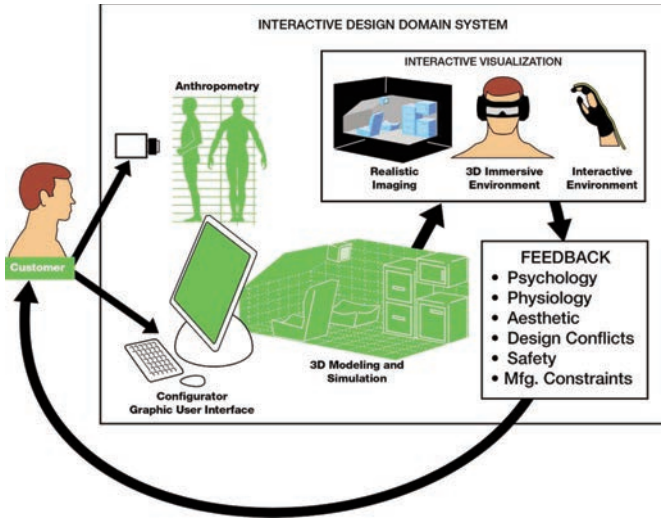
In an Open-Architecture Product (OAP), components can be added to the original product platform. The iPhone, introduced in 2007, has an open-architecture software platform that allows Apps to be added. OAPs that offer the option of adding or changing hardware components can create new and good jobs, as follows:

1 The Original Equipment Manufacturer of an open-architecture product builds a platform that accommodates the product's main functions and establishes interface standards that enable potential developers to integrate their innovative hardware components
2 Domestic companies invent and produce the components, thereby creating new local jobs
3 Components are integrated into the main product to adapt it to new uses

Create New, Good Local Jobs!

The interior of an automobile exemplifies a potential open-architecture product. An automobile manufacturer will delivers a car with the main functions – powertrain, chasis, steering, etc. An preserved empty space with interfaces for customized components and units

Small enterprises will invent and produce the units in the sketch on the left, subject to the interface requirements.



3. Technology for Peace

"A project Koren calls 'technology cooperation for peace' would bring together engineers from warring nations to work together toward a technological but humanitarian goal, such as improving irrigation. "They would become friends," Koren says. "It would be peace from the bottom up." The educator has seen such unlikely friendships take root in his own lab. Koren has been trying to move these ideas forward for years now. ***Perhaps their time is yet to come."***

– Nicole Casal Moore, UM Record, March 19, 2012

The ERC–RMS has had students from 36 countries; from India and Pakistan; Lebanon and Israel; Muslims, Christians and Hindus; all working together in teams that focused on solving technical problems. By working together they learned to respect one another and to see that the person on the other side of the conflict would also like to live in peace and prosperity.

The ERC working environment is an encouraging model: when participants from diverse backgrounds work together on joint projects, political and cultural boundaries are bridged.

The concept: Individuals from countries in conflict work together on common technology projects, thereby creating cooperation. The ultimate objective is to achieve peace and resolve conflicts.

The ERC–RMS supported students from 36 countries

PEOPLE WHO HAVE GOOD JOBS WANT TO LIVE IN PEACE

Mr. Aleksander Kwasnieski, former president of Poland (1995-2005), visited the ERC in 2006 to learn about modern manufacturing ("in terms a politician can understand") and found himself also learning about peace. Our students, Aftab Khan (Muslim from Pakistan) and Niresh Agarwal (Hindu from India), worked as a coherent team. "How come?" he asked. The answer: "We discuss only technical issues, and we became friends."

Imagine all the people living life in peace...
You may say I'm a dreamer
But I'm not the only one. —John Lennon
The Beatles

Koren made two attempts to propose an action plan:

1 In 2002, Liz Cheney (the daughter of former Vice President Dick Cheney) was appointed Deputy Assistant Secretary of State for Near Eastern Affairs. One of her objectives was to promote peace initiatives. At that time Dr. E. Shakour was a professor at Mar Elias Educational Institutions, Ibillin, Israel, and had connections to universities in Jordan and Bethlehem. Koren and Shakour proposed to Cheney's Department establishing mixed teams composed of Israeli, Jordanian and Palestinian students to work on joint agricultural projects. Their project was declined.

2 At a presentation to NSF in 2004, Koren proposed the establishment of a new type of NSF Center, to be known as Cooperative Education & Research Centers for Science & Technology Embracing Peace (STEP). Koren held a serious discussion with Arden L. Bement, NSF Director, and NSF Assistant Directors for Engineering, Education, Social Sciences, and other relevant areas. Their conclusion was that the NSF should add this concept as a component to existing NSF Centers. Koren saw it as a kiss of death for his proposal.

Was this a case of bad timing? Perhaps the time for this initiative is yet to come.

PEOPLE WHO LIVE IN PEACE WANT TO HAVE GOOD JOBS

Koren's Ph.D. Students

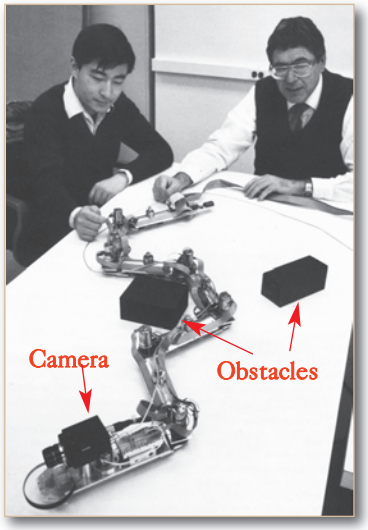
Professors at universities

Moshe Shpitalni	Technion, Israel
Oren Masory	Florida Atlantic University
Moshe Shoham	Technion, Israel
Johann Borenstein	University of Michigan
Chih-Ching Lo	Feng Chia University, Taiwan
Rong-Shine Lin	National Chung Cheng University
Shraga Shoval	Ariel University, Israel
Sungchul Jee	Dankook University, Korea
Byung-Kwon Min	Yonsei University, Korea
Valerie Maier-Speredelozzi	University of Rhode Island
April Bryan	University of Western Washington
Oben Ceryan	Drexel University, Philadelphia, PA

Leaders in Industry

Aaron Bar	Orthofeet, NJ
Yansong Shan	Coolex, Inc., CA
Lijiang Larry Feng	Cisco, TX
Tom Weber	Webertech, WY
George O'Neal	TRW, CA
Catherine Ling	General Motors, MI
Ilkiu Huh	Samsung, NY
Patrick J Spicer	General Motors. MI
Gil Abramovitch	General Electric, NY
Li Tang	Bank of America, NC
YuanHung Kevin Ma	Teco Group, Taiwan
Selin Kurnaz	Ernst & Young, NY
Vijay Srivatsan	Bloom Energy, CA
Xiaowei William Zhu	Travelers Indemnity, CT

Moshe Shoham (left), Koren's Ph.D. student, invented a spine surgery robot that is shown to B. Netanyahu, Israel Prime Minister, and P. Lavi, Technion President, 2012



Koren and his Ph.D. Student Yansong Shan demonstrated the world's first snake robot, 1992

Alon Wolf, Shoham's Ph.D. Student (Koren's academic grandson) demonstrates his snake robot to President Obama, 2013

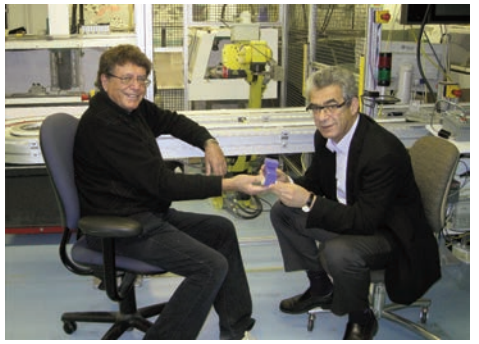
… with Johann Borenstein and CARMEL

"in 1987 Yoram founded the UM Mobile Robotics Lab. His IEEE seminal paper, *The Vector Field Histogram* (CARMEL technology) has 1600 citations, the highest citation score among his published papers."

J. Borenstein in the Dedication Ceremony of Koren Conference Room

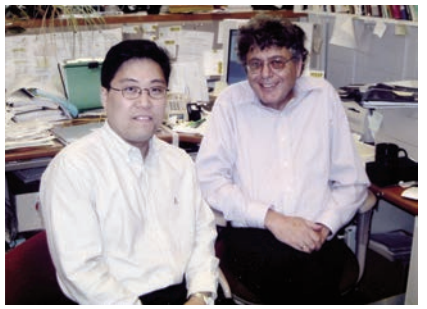
Valerie Maier-Speredelozzi, Koren's Ph.D. Student, a professor at the University of Rhode Island

Oren Masory (right), Koren's Ph.D. student, demonstrates CNC simulation for Dr. Gene Merchant. Technion, 1977



… with Moshe Shpitalni, Koren's 1st Ph.D. student (Dean of the Technion Graduate School, 2006 - 2012)

Rong Shine Lin, a professor at National Chung Cheng University, Taiwan at KorenFest, May 2007 (see page 25)



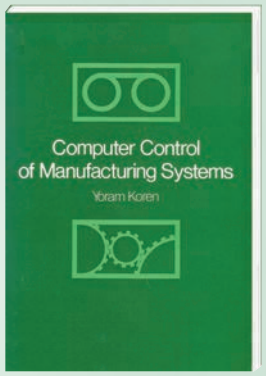
...with Byung-Kwon Min at Koren's office (2002). Min is now a Professor at Yonsei University in Korea

Sungchul Jee, Koren's Ph.D. Student, professor at Dankook University, Korea

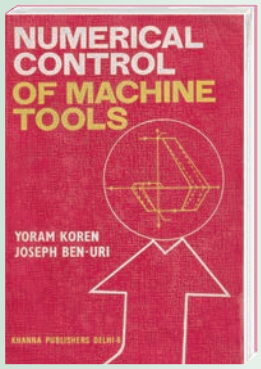
Tom Webber, Koren's Ph.D. student, is a renown industry entrepreneur

Koren's Books

Koren's first book, ***Numerical Control of Machine Tools***, describes various NC sub-systems for professionals. His second book, ***Computer Control of Manufacturing Systems***, 1983, is a textbook that summarizes his pioneering research from 1970–1982. Numerous universities worldwide adopted this book as the textbook on this topic, and today, 30 years after its publication, it is still being published and studied. Tens of thousands of students have learned about the scientific aspects of CNC from this book.



Published in 1983 by McGraw Hill, NY



Published in 1978 by Khanna

SME Textbook Award, 1984

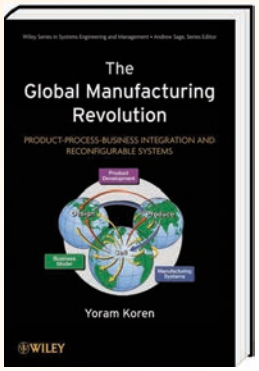
"A number of Koren's former students reports that twenty years after graduation they keep his books within reach at their desks because they consult them regularly."

—Provost Phil Harlon, March 27, 2012

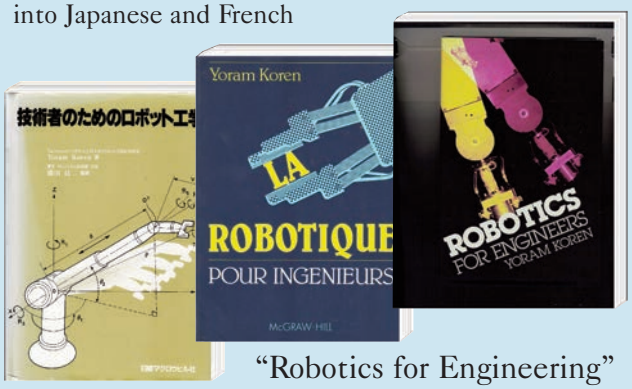
The Global Manufacturing Revolution, published by Wiley in 2010, is the textbook used in the graduate course on Global Manufacturing initiated by Koren in 1995. The book proposes engineering technologies and strategies that can increase an enterprise's speed of responsiveness to volatile markets. The mathematical tools, theories and case studies in this volume are invaluable to engineers who wish to pursue leadership careers in the manufacturing industry as well as to business school students who are motivated to lead enterprises.

The Global Manufacturing Revolution is the first book to focus on:

- Impact of globalization on enterprises
- Reconfigurable manufacturing
- Integration of product design, the manufacturing system, and business issues



Published in 1985 by McGraw Hill, with translations into Japanese and French



"Robotics for Engineering"

Dori Book Award, 1985

Koren's book ***Robotics for Engineers*** (1985, McGraw Hill) is perhaps the first book that elaborated on the mathematical principles of robot arms. It was extremely popular in the first years after its publication, and was translated by the publisher into Japanese and French.

The Dreams of Manufacturing Science Giants

Eugene Merchant, Alina, Helen Merchant and Yoram, 2001

Dr. Eugene Merchant's contribution to modern manufacturing is legendary. In the early 1940's he developed the basic theory of metal-cutting, which made it easier for engineers to determine the type of tooling needed to provide the optimum cut and how to regulate the power needed to make a cut. His theory is still considered the best available for explaining the machining process

Eugene's **DREAM** in the late 1950's was to develop computer-integrated manufacturing systems, which has become the standard operating practice for manufacturers all over the globe.

Leaders inspire others to dream

Yoram and Alina (left), Sam and Daisy Wu (right), Madison WI, 1975

Professor Shien-Ming (Sam) Wu pioneered the insertion of real-time statistics into practical manufacturing systems, thereby enhancing product quality. In the late 1980's the body precision of the Big-Three automobiles was 6 to 8 mm, where the precision of some foreign automobiles was 3 to 5mm

Sam's **DREAM** in the 1980's was to achieve a precision of 2 mm for auto bodies of US automobiles, rather than 6 to 8 mm. In 2000, his dream has become the norm for US automotive industry.

"*Why only 2 mm and no better?*" Yoram asked him. "*We can achieve 2 mm by improving the production methods,*" he answered. "*A reduction below 2 mm is not achievable by improved production, but by other means.*" Professor Wu's dream was based on engineering principles. But Prof. Wu died before his dream could be realized. His dream was realized by his students, who were assisted by industry leaders, including Gary Cowger and Dwight Carlson.

The RMS Dream Team

Koren with ERC Deputy Director Galip Ulsoy
at the ERC–RMS inauguration, July 1996
(See page 25 how Koren and Ulsoy met)

Inauguration of the RMS testbed, 1998
(L to R) Galip Ulsoy, Yoram Koren,
U.S. Senator Spencer Abraham, CoE Dean Steve Director

"The ERC–RMS is the first ERC that the CoE won. This is a milestone in the College history!"

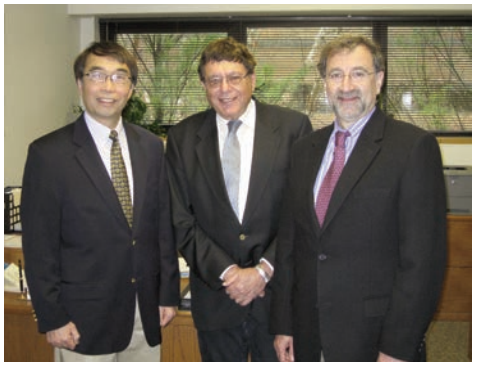
—Former CoE Dean Steve Director in the celebration of 150 years of engineering at U-M, 2004

ME Faculty working at the ERC–RMS

Standing (L to R): Wencai Wang, Jack Hu, Albert Shih, Elijah Kannatey-Asibu, Jun Ni. Sitting (L to R): Galip Ulsoy, Yoram Koren, Dawn Tilbury

Galip Ulsoy was ERC Deputy Director from 1996–2002, and 2006–2007, Jun Ni was ERC Deputy Director from 2003–2005.

...with Zbigniew Pasek (standing left), James Moyne (standing right), Judy Jin (sitting left) and Amy Cohn (sitting right)



... with Kon-Well Wang (ME Chair) and Panos Papalambros (ME Chair, 1992–98)

… with Mike Molnar of Cummins; now Chief Manufacturing Officer, NIST

Stephen Malkin, U–Mass Distinguished Professor Emeritus, NAE Member and Koren's close colleague

Industry Friends

Meetings with industry members were held twice a year

ERC–RMS Industry Meeting, 2004

"The ERC has created a working environment, which has impacted a slow moving industry."

—Industry Report to NSF, 2002

ERC–RMS Executive Committee, 2006

Standing (Left to Right): John Schweikert (Executive Director, GM), Mark Blair (Director, Ford), Robert Swanson (Director, MEDC),Larry Seiford (IOE Chair).

Seated(Left to Right): Rick Collins (Director, Chrysler), Susan Smyth (Chief Scientist of Mfg, GM), Yoram Koren (Committee. Chair), Stephan Biller (GM, now at GE), David Munson (Dean, UM CoE)

… with Jacques Nasser (right),
former President, Ford Motor Co., 2000

Presenting RMS research for former U–M President James Duderstadt. (On the left Pat Spicer, Koren's Ph.D. student, now at General Motors.)

Professor Jim Duderstadt served as Dean of the College of Engineering 1981- 1986, and as U–M president 1988-1996.

Homer Neal,
U-M Interim President 1996-97, visits the ERC–RMS

NAE members Yoram Koren and Don Chaffin (right), welcome new NAE members, Gary Cowger (GM, center left) and Galip Ulsoy (U-M). April 2006.

The RMS Center has held three CIRP–sponsored Reconfigurable Manufacturing Conferences with participants from 40 countries.

Panel at the 1st CIRP-sponsored International Conference on Reconfigurable Manufacturing, 2001

Yoram Koren sits between Kiko Harashimi, President of Honda N. America, and Francesco Jovane, CIRP President

International Conferences on Reconfigurable Manufacturing

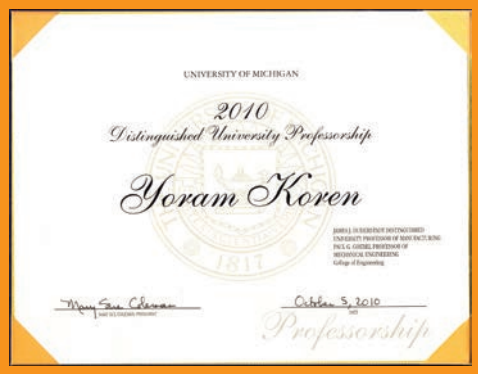
...with A Niimi, President of Toyota N. America, at the 2nd conference on RMS, 2003

...with Roman Krygier, Group VP, Ford at the 3rd conference on RMS, 2005.

170 participants, of which 65 from U.S. industry

Koren's Honors and Awards

NAE Member, 2004



University of Michigan Distinguished University Professor, 2010

Merchant Medal by ASME & SME, 2006

Hanasufa Outstanding Investigator Cup, 2004

SME Gold Medal, 2007

William Ennor Award, 1999

CIRP Fellow 1985
SME Fellow 1987
ASME Fellow 1990
IEEE Life Fellow 2013

Paul G. Goebel Endowed Professor of Engineering, 1993

CoE Attwood Award, 2008

CoE Excellence in Research Award, 1992

… with U-M President Mary Sue Coleman (left) inauguration as James J. Duderstadt Distinguished University Professor of Manufacturing, 2010

Distinguished University Professor, 2010

Distinguished University Professor ***recognizes exceptional scholarly and creative achievements***. The University of Michigan has 50 DUPs that are selected by the Provost.

Provost Phil Hanlon introduces Koren before his DUP Lecture "***On Dreams and Timing***" on March 27, 2012

The Provost's quotations in this booklet are taken from his introduction to Koren's speech and are based on letters received for Koren's DUP nomination.

Election to the National Academy of Engineering, 2004

Koren's inauguration as an NAE Member
(l - r) W. Wulf, NAE President, Y. Koren, and
C. Barrett, NAE Chair and CEO of Intel Corp.

Attwood Award, 2008

The Stephen Attwood award is the highest honor of the College of Engineering at the University. The award recognizes:
"Extraordinary achievements that have brought distinction to the College and University."

...with the College of Engineering Dean, Dave Munson at the Attwood Award ceremony--

KorenFest, May 2007

In honor of Yoram, Prof. Galip Ulsoy organized a splendid festival after the last NSF site visit in May 2007. Colleagues talked about Yoram for hours, before attending an enjoyable dinner.

What do you think about Yoram's party?
"For five hours I listened to how good Yoram is, I almost started to believe..." — Alina Koren

Front to Back and Left to Right:

Yoram Koren, Alina Koren, Galip Ulsoy

Elijah Kannatey-Asibu, Bruce Kramer, Jeff Stein, Daisy Wu, Jun Ni

Mike Molnar, Dave Dornfeld

Burak Ozdoganla, Deniss Assanis

Rich Furness, RS Lin, Steven Liang

Modhu Ramesh, Daryl Weinert, Stephen Segall, Jan Shi

Remarks at Koren Conference Room Dedication Ceremony, 2012

"I know that one important factor in Yoram's success is that he has a wonderful boss and companion—that is Alina. In fact, Yoram told me many times that Alina is his Strategic Advisor who always keep him on the right path."

Kon-Well Wang, Timoshenko Professor and Chair of Mechanical Engineering

"A true leader in research is someone who creates a new research field that others follow. Prof. Koren is such a leader. He conceived the Reconfigurable Manufacturing Systems that became a major research field. His 1999 CIRP keynote paper "Reconfigurable Manufacturing Systems" has over 1,000 citations."

Jack Hu, Anderson Professor of Manufacturing and Associate Dean of Engineering

"My Ph.D. research at Illinois built off Yoram's Cross-Coupled Control original approach (see page 6). Following the presentation of my work at a conference, the session chair informed me that Yoram Koren is in the audience. I must admit at that time I felt as though I had had a rock star in the audience."

Kira Barton, Assistant Professor of Mechanical Engineering

Yoram and Alina Koren Conference Room

"In the mid 1970's Professor Koren had already published high-impact papers on flank wear estimation, on the design of drives for CNC, and the first scientific paper on interpolators for CNC machines (*IEEE Trans. Computers*, 1976). And he had started writing his book *Computer Control of Manufacturing Systems* – a classic textbook, still widely used today.

These would be amazing accomplishments for anyone over an entire career. What is even more amazing is that **this was only the beginning**. You will hear from other speakers how he went on to do equally amazing things in reconfigurable manufacturing, and in robotics.

Galip Ulsoy, Distinguished University Professor

Ribbon Cutting Ceremony Opening the Koren Conference Room
(L to R): Jack Hu, Galip Ulsoy, Dave Munson, Alina Koren,
Yoram Koren, Panos Papalambros and Kon-Well Wang

Students having a project meeting in Koren Conference Room

1980: Alina's Advice and Jim Duderstadt's Letter

In 1980 the Korens reached a critical juncture in their life. Here is Yoram's story:

"I was entitled to a sabbatical from the Technion, and in January I toured four potential places to spend my Sabbatical. By April I had four written offers, and I had to decide. The most generous financial offer was from the legendary CEO of Unimation, Joe Engelberger (the inventor of the PUMA robot), who wanted me to implement CNC technologies in his new generation industrial robots. The three academic offers were from Dave Pratt (ME Chair, U-M), from Carnegie Mellon University (that initiated its robotics center in 1980), and from RPI (the best financial offer of the three universities). The offer from U-M was for an endowed chair: Visiting Paul Goebel Professor of Engineering. Fortunately, I live with an exceptional strategic advisor (Alina), who suggested that I accept the U-M offer. In August 1980 we came to Ann Arbor (for one year).

Dave Pratt suggested that I cooperate with a new Assistant Professor (who had also joined the department in August 1980) on real-time adaptive control for machines. 'His name is Galip Ulsoy,' Dave said. Both Galip and I listened to Dave, and we have been collaborating since then.

In the spring of 1981 James Duderstadt was appointed Dean of Engineering and revolutionized the College. I was granted a one-year leave of absence from the Technion and stayed until October 1981. Jim was concerned about the migration of manufacturing and robotics technology to Japan, and in 1981 he established the Center for Robotics and Integrated Manufacturing, directed by Dan Atkins. CRIM had three divisions:

1 Robotics (Director: Dick Volz)
2 Integrated Design and Manufacturing (Director: Yoram Koren)
3 Manufacturing Operations (Director: Dick Wilson)

Jim Duderstadt took me to visit local manufacturing industries, where he was treated like a king. After my return to Israel, Jim wrote me (October 19, 1982):

'I want to express my personal gratitude for the outstanding contributions you have made over the last two years. You played a very major role in determining the intellectual thrust and providing the leadership so necessary to get our CRIM off the ground. The leadership and energy you provided to this effort has given it strong momentum. I must say that I learned a great deal about manufacturing from conversations with you.

I would hope that you would keep us in mind in the future. If there should be a possibility that you might be able to visit us once again, please don't hesitate to let us know immediately.'

I did."

Koren's Family

Rony, Mayan, Rily, Eytan, and son, Shlomy, in Costa Rica

Shlomy and his wife Rily are exemplary parents who educate their three children quietly but firmly. They live in Tamarindo, Costa Rica. Shlomy is the chef and owner of his own restaurant, "Season's by Shlomy," the best restaurant in the area. The entire family speaks English, Spanish, and Hebrew. Shlomy also speaks fluent French – he graduated from the Cordon Bleu in Paris.

Asi attented Tappan Middle School in Ann Arbor, Michigan, before returning on her own, at age 15, to Israel, where she finished high-school, with high grades. Right afterward she was drafted and proudly served in the Israeli army for two years, during which she reached the rank of sergeant, and was awarded an Outstanding Soldier certificate – an honor granted only to very few soldiers. Today she maintains a home in northern Israel for women suffering from addiction and other maladies.

… with daughter Asi (Esther)

Alina
Strategic Advisor

Alina was a high school teacher and a Lecturer at universities in Israel and at the University of Michigan.

Yoram has a B.Sc. (1965) and M.Sc. (1968) in Electrical Eng. and a D.Sc. (1971) in Mechanical Engineering (Advisor: Prof. Ehud Lenz) Technion, Israel Institute of Technology

Yoram Koren's website: http://sitemaker.umich.edu/ykoren/home

College of Engineering, the University of Michigan
April, 2014