Projects in History of Automatic Control

Johansson, Karl Henrik; Åström, Karl Johan

1997

Document Version:
Publisher's PDF, also known as Version of record

Link to publication

Citation for published version (APA):
Johansson, K. H., & Åström, K. J. (Eds.) (1997). *Projects in History of Automatic Control*. (Technical Reports TFRT-7561). Department of Automatic Control, Lund Institute of Technology (LTH).

Total number of authors:
2

ISSN 0280–5316
ISRN LUTFD2/TFRT--7561--SE

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Karl Henrik Johansson
Karl Johan Åström
(editors)

Department of Automatic Control
Lund Institute of Technology
June 1997

Department of Automatic Control
Lund Institute of Technology
Box 118
S-221 00 Lund Sweden

Document name
REPORT

Date of issue
June 1997

Document Number
ISRN LUTFD2/TFRT--7561--SE

Author(s)
Karl Henrik Johansson
Karl Johan Åström

Supervisor

Sponsoring organisation

Title and subtitle
Projects in History of Automatic Control

Abstract

This report summarizes the projects in the course History of Control given in the spring of 1996. There was a standard project whose purpose was to give some perspective on the recent developments of the field through study of the contents of the major conferences in Automatic Control. Some students also suggested their own projects, development of an interactive representation of the history of control (The Control Tree) and reflection on the development of control through some awards. Then projects were performed in groups.

Key words

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title
0280–5316

ISBN

Language
English

Number of pages
99

Recipient's notes

Security classification

The report may be ordered from the Department of Automatic Control or borrowed through:
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Contents

Projects in History of Automatic Control

Karl Johan Åström

The purpose of the project is that you should spend some time to study the contents of the major conferences in Automatic Control and try to find some perspective on the development by studing the themes of the sessions.

The major conferences are:

IFAC The IFAC World Congress which is held every third year

ACC The American Control Conference, Held yearly

CDC The IEEE Conference on Decision and Control, Held yearly

There are also many other important conferences such as the European Control Conference, the Asian Control Conference but they have only started recently. There are also many specialist conferences organized by IFAC and IEEE.

I would like you to make a table which shows how the major themes have developed over a period. You could also write a page with some personal reflections.

Since the IFAC is held only every third year, I suggest that we stick to the IFAC years they are 1960, 1963, 1966, 1969, 1972, 1975, 1978, 1981, 1984, 1987, 1990, 1993 and 1996.

You are wellcome to work in teams. You may find it convenient to use a spread sheet to organize your data. In this way we can also merge all data into one report.

History of Control: Projects 1996

This is the current project list. The standard project is to make an assessment of the field of automatic control by investigating the contents of the major conferences and how they change over time. The conferences we look at are the IFAC World Congress (IFAC), The American Control Conference (ACC) and the IEEE Conference on Decision and Control (CDC). Please notice that we have ACC from 1962 and CDC from 1972, all IFAC Congress Proceedinga are however available. There are also special projects.

The Control Tree

- Lotta Johnsson
- Hélène Panagopoulos

Some Awards in Automatic Control

- Lennart Andersson
- Johan Nilsson
- Anders Robertsson

The standard project 1960 (only IFAC) and 1978

- Jörgen Malmborg
- Anders Wallén

The Standard Project 1963 (Only IFAC and ACC) and 1981

- Christian Rosén
- Harald Scherer

The standard Project 1966 (Only IFAC and ACC) and 1984

- Jonas Eborn
- Martin Öhman

The standard Project 1969 and 1987

- Mattias Grundelius
- Kalle Johansson

The Standard Project 1972 and 1990

- Mikael Johansson
- Mats Åkesson

The Standard Project 1975 and 1993

- Johan Eker
- Erik Gustavsson Cao Yong

History of Automatic Control – statistics of 1960 and 1978

Anders Wallén
Jörgen Malmborg

June 5, 1996

This is a project report in the course History of Control. Our part was to study the proceedings from IFAC '60 and '78, CDC '78 and ACC '78. As there was no CDC and ACC 1960 it is difficult to conclude any significant trends. However, a few interesting observations are listed below.

We have divided the sessions into 6 categories, System Theory, Modelling and Identification, Controller Design Methods, Controller Components, Applications and Other. Other meaning difficult to sort. The proceedings of ACC '78 and IFAC '60 are not organized in sessions. Instead we tried to classify the ACC papers from their titles. The IFAC '60 papers were also sorted by the number of papers in each category.

Comparing IFAC '60 to IFAC '78 we can notice a decrease in 'pure' system theoretical papers. A reason for this is the classification scheme itself. 1978 many of the papers are sorted into specific controller design methods while 1960 they were just control theory.

In IFAC '60 it was popular to write papers on controller components such as sensors, actuators and instruments. In '78, controller components meant almost exclusively computer hardware and software.

Among the '78 conferences, CDC was the one with largest emphasis on control theory.

Some sessions are typical to the era. 1978 we have papers like: Control Theory Encounter of the Third Kind and Catastrophe Theory. An interesting session name in IFAC '78 is Copenhagen Central Mail Sorting Office.

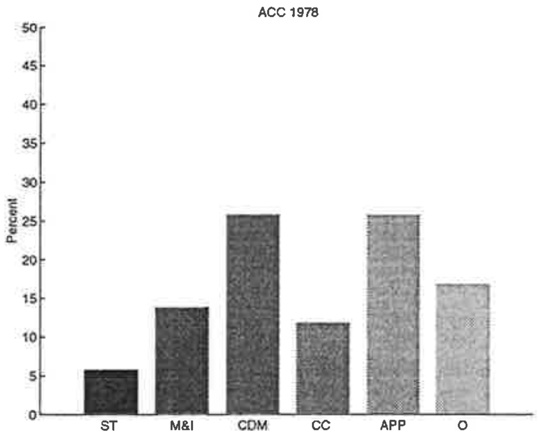
The first IFAC includes milestones like Pontryagin's paper on the Maximum Principle, LaSalle's on The 'Bang-Bang' Principle and Kalman's On the General Theory of Control Systems.

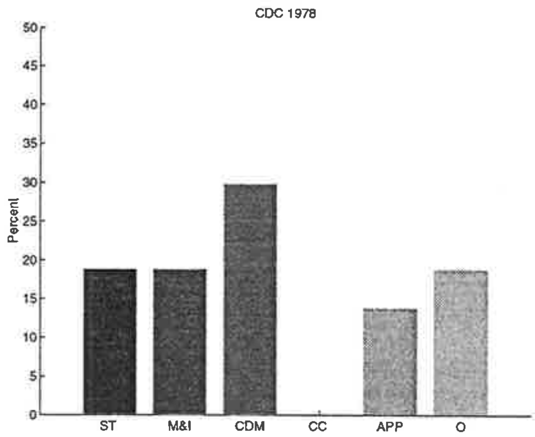
A. Statistics - Diagrams

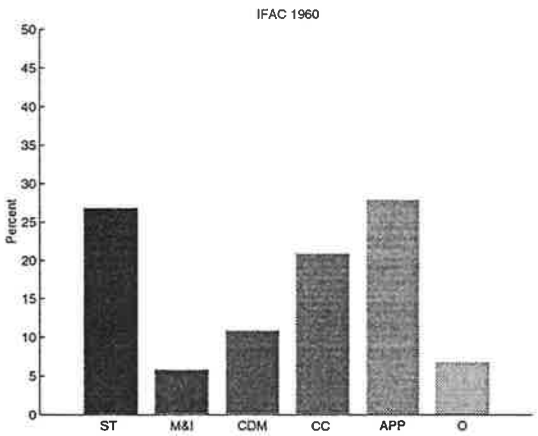
Legend

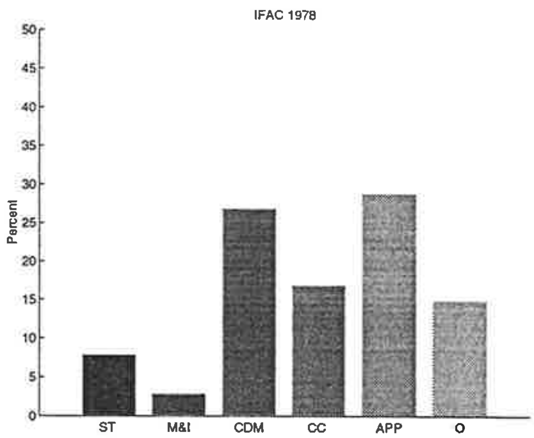
ST	System Theory
M&I	Modelling and Identification
CDM	Controller Design Methods
CC	Controller Components
APP	Applications
O	Other

For detailed statistics on session subjects see appendix B.









B. Statistics - Details

ACC 1978, Philadelphia

System Theory	8
Modeling and Identification	19
Controller Design Methods	36
Controller Components	16
Applications	36
Others	23
	138

CDC 1978, San Diego

System Theory		**8**
Multivariable	2	
Linear Systems	3	
Nonlinear Systems	2	
Other	1	
Modeling and Identification		**8**
Controller Design Methods		**13**
Robust	1	
Adaptive	1	
Optimal	4	
Stochastic	1	
Decentralized	1	
AI	1	
Filtering	4	
Controller Components		**0**
Applications		**6**
Power Systems	1	
Vehicles	2	
Robotic Control	1	
Other	2	
Others		**8**
Numerical Analysis	1	
Bifurcation Theory and Catastrophe Theory Methodology	1	
Mathematical Physics and System Theory	1	
Man in the Loop	1	
Traffic planning and Monitoring	1	
Biological Systems	1	
Planning	1	
Monitoring fault detection and diagnosis	1	
		43

IFAC 1960, Moscow

System Theory		**75**
Linear Systems	23	
Nonlinear Systems	14	
Discrete Event	25	
Other	13	
Modeling and Identification		**18**
Controller Design Methods		**32**
Adaptive	20	
Optimal	12	
Controller Components		**58**
Instruments	19	
Computing	18	
Sensors and Actuators	21	
Applications		**79**
Manufacturing Systems	51	
Power Systems	24	
Vehicles	4	
Others		**19**
Structure and Signal Composition	7	
Simulation	12	
		281

IFAC 1978, Helsinki

System Theory		**5**
Multivariable	2	
Other	3	
Modeling and Identification		**2**
Controller Design Methods		**16**
Robust	1	
Adaptive	3	
Optimal	5	
Stochastic	1	
Decentralized	4	
Filtering	1	
Other	1	
Controller Components		**10**
Instruments	1	
Computing	8	
Other	1	
Applications		**17**
Manufacturing Systems	8	
Power Systems	4	
Vehicles	5	
Others		**9**
Traffic planning and Monitoring	2	
Biological Systems	3	
Control Systems Methodology	3	
Education	1	
		59

Development of Research Subjects in the Field of Automatic Control

IFAC congresses 1963 & 1981

The following text is an attempt to summarise the contents of the contributions in the field of automatic control presented at the congresses of the International Federation of Automatic Control (IFAC) in the years 1963 (the second session) and 1981 (the 8th session). The purpose was to look at the subjects research efforts have been made in the 2÷3 years before the results were made available to the interested public. The subjects treated give a rather good image of the engineering problems that had high priority in the time period considered. At the same time they point out areas of further interest where efforts should be directed to. A few charts reflecting the distribution of papers related to the different subjects help to get an overview of the volume of contributions and they allow to get at least a gut feeling of where research emphasis was put. Apart from strict technical results it is interesting to note how the general spirit in which the congresses took place where influenced by political and economical factors specific for the period under consideration.

2nd Congress on Automatic and Remote Control
Basle, Switzerland, 1963

General Remarks and Facts

The second IFAC congress is definitely characterised by the pioneering enthusiasm the organising committees and participants showed, certainly being inspired from a rather fruitful and promising start marked by the first international conference of this kind, which was held three years earlier in Moscow (1960). The political climate made it possible to have a relatively large number of participants from the eastern block countries at the congress. To give an example: the number of authors from the former USSR was 36 of the total number of authors, that was 196.
In the "Address of Welcome" the president of IFAC mentions general figures about the congress. He says: "...1476 participants and 200 ladies are present ..." coming from 32 countries from all over the world. A total amount of 159 papers has been presented at the conference comprising about 1,5 million words to be checked for correct translation and/or spelling. The expenses of the conference summed up to 97,000 US$, pre-prints and the 11 survey papers included.

The congress basically covered three important fields:

- Theory
- Applications
- Components

The contributions were grouped into a volume containing theoretical papers whereas the application and component papers have been published in the second volume of the proceedings.

Subjects of presented work

It is interesting to take a closer look at the individual problems that are part of the conference fields above researchers focused their attention on.

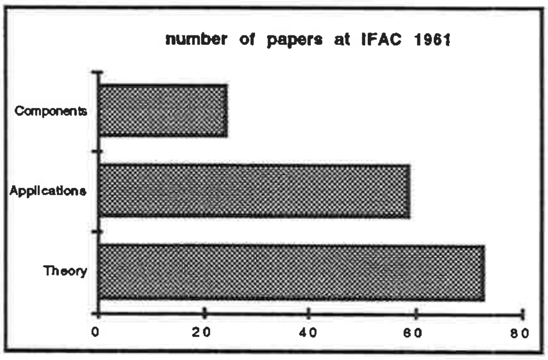


Figure 1. Numbers of papers according to their grouping in different fields, IFAC 1963

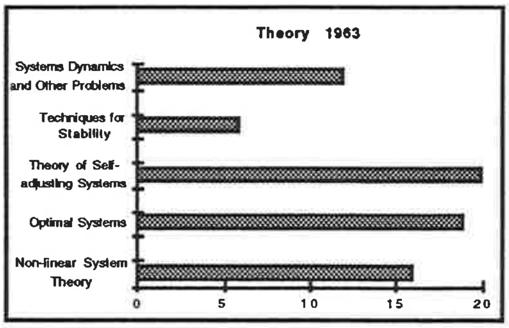
It is interesting to note that a relatively large number of papers dealing with **component development** (see figure 1) are part of the problems treated in the forum offered by the IFAC congress.

Mechanical, hydraulic and pneumatic devices as well as electromagnetic devices are still standard components used in practical applications. New electronic components (semiconductor based circuits) are on the way to dominate and digital controllers gain more and more attention. Strongly related to the component side are subjects of process instrumentation and component reliability.

Volume 1 of the proceedings is dedicated to the **theoretical contributions**. They comprise important work in the field of non-linear system theory, stochastic sand discrete systems. Optimal system synthesis has a representative weight in the research efforts, as well as self adjusting systems. Invariance problems and learning problems of adaptive systems are the focus of attention. A few papers on system stability analysis and general system dynamics are also present.

As far as the **application** field is concerned a relatively large amount of work has been devoted to the electric utility field, including two papers dealing with nuclear reactor control. Important attention has the process industry, with steel, chemical and oil industry as 'classical' fields of application. Automation of manufacturing processes is recognised as a successful area of application, and attention is given to the man-machine systems, that is basically the 'man-in-the-loop' problem. Attempts to model the human operator are present in a few papers.
Automatic control of aerospace systems includes flight and satellite control as well as control of radio-telescopes.

Figure 2 illustrates a more detailed view of the topics treated in the different congress fields.



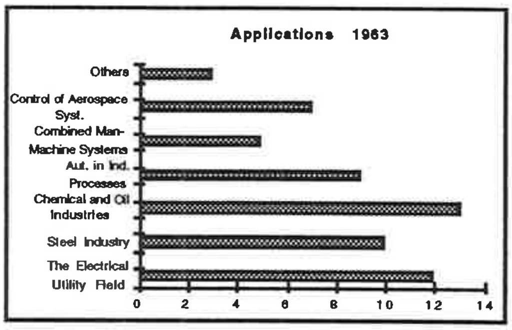


Figure 2. Numbers of papers in the different problem areas of the theoretical (to the left) and application field (to the right), IFAC 1963

Conclusions

It is appropriate to say that relatively simple systems have been tried to analyse thoroughly and into the smallest details. The years around 1963 are characterised by developments in the areas of aerospace flight and automation of industrial processes.

The "space race" stimulated a lot of research of which just a small amount of results have been made accessible to the large public. However, the enthusiasm of the organisers is not to be overlooked and it is good to see that engineering people have been (at least some of them) aware of the impacts of their activity on society in general. It is a lesson that should be learned perhaps even more in our days. A few extracts of what some speakers mentioned are worthwhile to replicate in the following:

H. Chestnut (first president of IFAC)

"... however, I should like to point out two other fields for serious attention by control people. These are:
(1) The need for 'optimising the process of making automatic control', i.e. bridging the gap between theory and practice.
(2) The need for working with qualified people in the social, economic, and political fields to help make the net effect of automatic control and automation a cause for hope rather than a reason for fear ..."

A.M. Letov (second president of IFAC)

"... Although it may be in 90 years time, I still hope fervently that I can live to the noteworthy day when the IFAC Congress will have gone round all the countries in our Federation and returned once again to Russia - perhaps to Moscow - involving not 2,000 but 20,000 of participants. I look forward to the day linguistic difficulties of communication will have been overcome ... You will say it is a very remote dream. ... Let me just say this. ... you are all people who do creative work - dreamers - and all the plans you implement so wonderfully begun with a dream. ..."

8th Congress on Automatic and Remote Control
"Control Science and Technology for the Progress of Society"
Kyoto, Japan, 1981

General Remarks and Facts

The 8th IFAC congress has been held in Japan and already by the number of published volumes (7) the contributions finally made up, one can guess that the IFAC congresses as such attracted many more researchers to present results of their work, despite the fact that automatic control continuously grew as a field for engineering activity.

In the "Welcoming Address" some important aspects are mentioned, that characterise the time period the congress had been held:

"... Especially in recent years, automatic control engineering, combined with computer technology, has made a rapid progress and produced considerable results as a leading technology in the age of energy and resource saving, such as machine tools an industrial robots, contributing much to the improvement of the quality of life. However, for further development inspite of the recent severe economic conditions of the world, we have to solve a number of problems such as the improvement of industrial systems, the saving of energy and resources, the development of new energy source substituting oil, and the development of new materials and new techniques. ..."

About 1600 participants from 46 countries were registered at the congress. A total amount of about 600 papers has been accepted for presentation out of which 560 have finally been presented at the conference. The papers were grouped into 9 sessions, each with emphasis on different aspects and fields of automatic control. An *case study* session was also included.

- Control Theory
- Stochastic and Large Systems
- Design and Reliability Systems
- Mechanical Systems and Robots
- Aerospace and Transportation
- Process Control
- Electrical Power Systems
- Appropriate Technology and Education and Economic Management
- Biological, Medical and Environmental Systems

Subjects of presented work

It is interesting to take a closer look at what the different sessions actually aimed at.

The session on **Control Theory** (volume 1) comprises a vast area of research activity including linear and non-linear system theory, distributed parameter systems and work on methodology. Stability analysis and system stabilisation, observability, controllability and reachability round up the mathematical system theory contributions. Aspects of practical control system design are completed by computational methods and algorithms presented. A few papers on optimal control are also present, but a relatively significant amount of papers deal with estimation methods and system identification. Dynamic system modelling is treated as a separate subject of system analysis.

The **Stochastic and Large System** session (volume 2) covers several different topics. Adaptive control and estimation and large scale systems are the most frequent, but there are many papers on for instance fuzzy, stochastic and multivariable control.

Computer aided design of control systems and the reliability of systems are discussed in the **Design and Reliability** session (volume 3). Different computer algorithms and tools for design and analysis are presented.

The **Mechanical Systems and Robots** session (volume 4, part A) emphasises on robotics and control of electrical motors and drives. The plenary paper deals with the history, present and future of robots.

In the **Aerospace and Transportation** session (volume 4, part B), space related research is dominating. Many authors discuss different ways to control satellite attitude. Launch, orbit and re-entry control is also discussed. Noticeably there is just one paper on ship control.

The **Process Control** session (volume 5) is basically divided into steel industry and chemical industry applications. In the papers on control of steel industry systems different control methods are discussed, e.g. multivariable control and adaptive control. Disturbance rejection by self-tuning regulators and multivariable control and on-line simulation are some of the subjects discussed in the part dealing with chemical systems.

Control strategy, management and planning are the major topics in the **Electrical Power Systems** session (volume 6), that emphasise on large scale systems. Generating plant control is also discussed, but there are just a few papers on nuclear reactors and power plants. Maybe it is a consequence of the incident at Harrisburg some years earlier.

Surprisingly many papers in the **Appropriate Technology and Education and Economic Management** session (volume 7, part A) are about the human-computer interactions. Operator behaviour under stress and risk is one of the subsessions. The economic-oriented papers cover control and modelling of both macro and micro economics.

In the **Biological, Medical and Environmental Systems** session (volume 7, part B) control of water resources, water supply networks and waste water treatment are discussed. Unfortunately they are divided into different subsessions, which reflects the common inability to see water distribution and waste water treatment as different parts of the same integrated system.

Figure 3 below shows the number of contributions grouped into three basic areas - theory, applications and components - that to some extent allow a comparison of the amount and distribution of conference papers with earlier congresses.

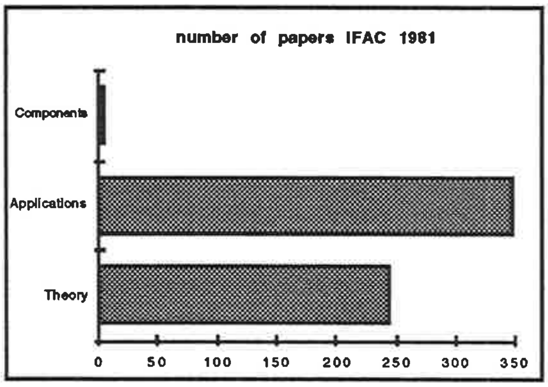


Figure 3. Numbers of papers according to their grouping in different fields, IFAC 1981

Papers regarding research on component and instrument are not presented at this conference. It seems that due to the large diversification of the development of components justified other forums for presentation of research results regarding components and instrumentation.

Figure 4 presents a bar chart where papers dealing with theoretical and application aspects appear according to their more detailed subjects they treat.

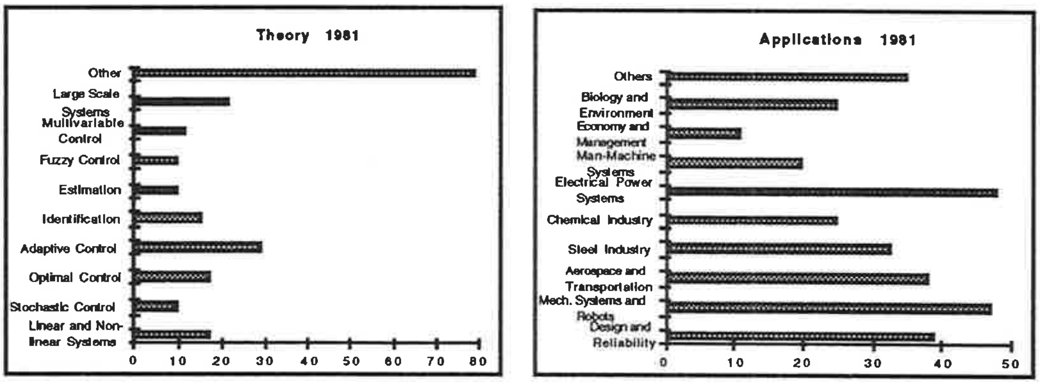


Figure 4. Numbers of papers in the different problem areas of the theoretical (to the left) and application field (to the right), IFAC 1981

Conclusions

Looking at the charts above it is clear that the field of control theory and technology is a dynamic field. The variety of topics in both theory and application shows that a lot of things are happening.

On adaptive control the research is intense, which is a result of the important theoretical contributions made in seventies and the fast development in microelectronics. The number of papers covering more complex dynamical systems, such as multiple input multiple output, large systems and process identification and estimation is significant. Aspects of modelling are also treated in some contributions.

In the application field the electrical power systems have a strong position, as a consequence of the strive towards efficient use and savings of energy. Process control continues to be important research area, as one of the classical areas of application of automatic control. Fields gaining more attention, compared to the early years, are economical, medical, biological and environmental systems, which are due to new possibilities offered by development of new theory and equipment. The awareness of environmental problems and responsibilities is of-course also a decisive factor leading to new research areas.

Robotics and research related to robotics are also well represented, which of course is due to the fast development in microelectronics, a fact that is pointed out by a speaker, Prof. Thoma, in his summary report:

"...Twenty years ago most of the papers were concerned with simple control methods such as feedback control and control technology of single input single output systems, which I like to call ' classical control' ... the advanced control science and technology... have tremendously expanded and changed. One important reason for that trend is the sophisticated development and at the same time extremely decreasing prices of microelectronic components... ('Third Industrial Revolution') ..."

Further he expresses some visionary thoughts, confirmed by developments up to present years:

"... It seems to me that most of the technical disciplines as well as a number of non-technical disciplines will be influenced by this development ..."

Raw Data of the Statistical Information from the Proceedings of the IFAC Congresses in the years 1963 and 1981

IFAC 1963

topic	Nr of papers
Theory	73
Applications	59
Components	25
total	**157**

IFAC 1981

topic	Nr of papers
Theory	225
Applications	321
Components	6
total	**552**

IFAC 1963

field of application	Nr of papers
The Electrical Utility Field	12
Steel Industry	10
Chemical and Oil Industries	13
Aut. in Ind. Processes	9
Combined Man-Machine Systems	5
Control of Aerospace Systems	7
Others	3
total	**59**

IFAC 1981

field of application	Nr of papers
Design and Reliability	39
Mech. Systems and Robots	47
Aerospace and Transportation	38
Steel Industry	33
Chemical Industry	25
Electrical Power Systems	48
Man-Machine Systems	20
Economy and Management	11
Biology and Environment	25
Others	35
total	**321**

IFAC 1963

Theory topics	Nr of papers
Non-linear System Theory	16
Optimal Systems	19
Theory of Self-adjusting Systems	20
Techniques for Stability Assessment	6
Systems Dynamics and Other Problems	12
total	**73**

IFAC 1981

Theory topics	Nr of papers
Linear and Non-linear Systems	18
Stochastic Control	10
Optimal Control	18
Adaptive Control	29
Identification	16
Estimation	10
Fuzzy Control	10
Multivariable Control	12
Large Scale Systems	22
Others	80
total	**225**

Trends in Control Conferences Checking up on '66 and '84

Jonas Eborn and Martin Öhman

As our project for the 'History of Control'-course we have gone through the proceedings of the Third IFAC World Congress 1966, AC Conference'84, CD Conference'84 and the Ninth IFAC World Congress 1984.

1. Overview of sessions

The main disposition of the sessions in the four conferences can be seen in Figure 1. What you can read from these graphs are time trends between the two IFAC congresses and that the different conferences attract slightly different audiences.

Differences between the IFAC congresses

In the eighteen years between the two World Congresses the control community has of course grown considerably and the total number of contributions to the World Congress has grown from 273 to 590 papers. In this time the hardware related papers has more or less vanished, probably to some other, more specialized forum (Instrument Society etc). Obscure hardware interest like pneumatic computers and similar has probably died out completely like the dinosaurs.

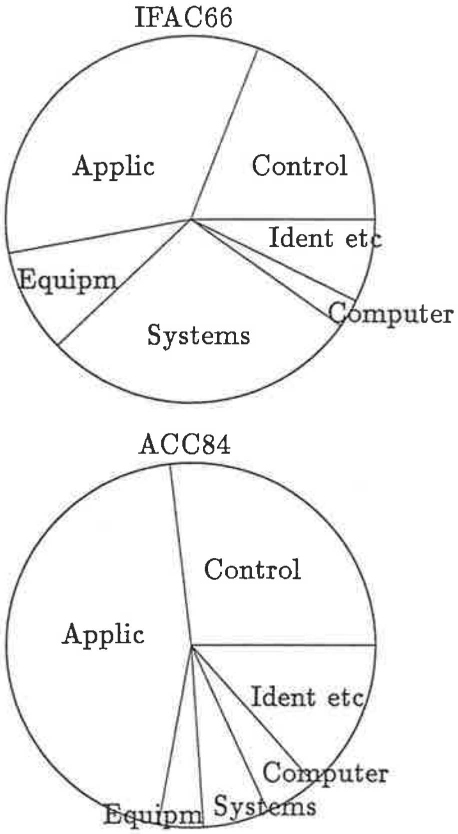


Figure 1 Pie charts of the contents in the studied conferences.

The parts pertaining to control design and algorithms and application specific papers has more or less kept their half of the interest while the other half has been reorganized. System theory attracts less attention while computer use, identification and other topics have grown considerably.

Differences between ACC, CDC and IFAC

As can be seen from Figure 1 the three major conferences have slightly different audiences. IFAC is very broad and attracts almost equal attention from theoreticists as well as practicists. It also attracts more of the obscure topics, like politics, social impact of control etc. ACC is a very practical conference with a lot of application papers while CDC is theoretical with a lot of interest focused on system theory as well as control theory and design.

2. A closer look at the topics

Control approaches at IFAC

The Third World Congress was held in 1966 in the 'golden era of optimal control'. Optimal control takes up more than half of the theory and design papers. Some papers are pertaining to robust issues although they use the term reliable control system instead. Adaptive control is just starting to attract interest and papers talk about both learning as well as adaptive systems.

If we compare this to the approaches used at the Ninth World Congress we see that optimal control is still very popular. It is still the largest design method used although its relative importance has decreased. What we today mean by robust control has started to attract interest and adaptive control is still very popular. Some so called 'intelligent' approaches has emerged, like game theory. There are also a number of other approaches like multivariable control and decentralized control, which together make up almost as large a portion as optimal control.

Applications at IFAC

If we take a look at what applications were popular in the two IFAC congresses we see that the relative size of the four first ones has been practically the same. Power system has retained its part and thus grown relative to the other applications. Control has also spread into a number of new application areas, which totals to the

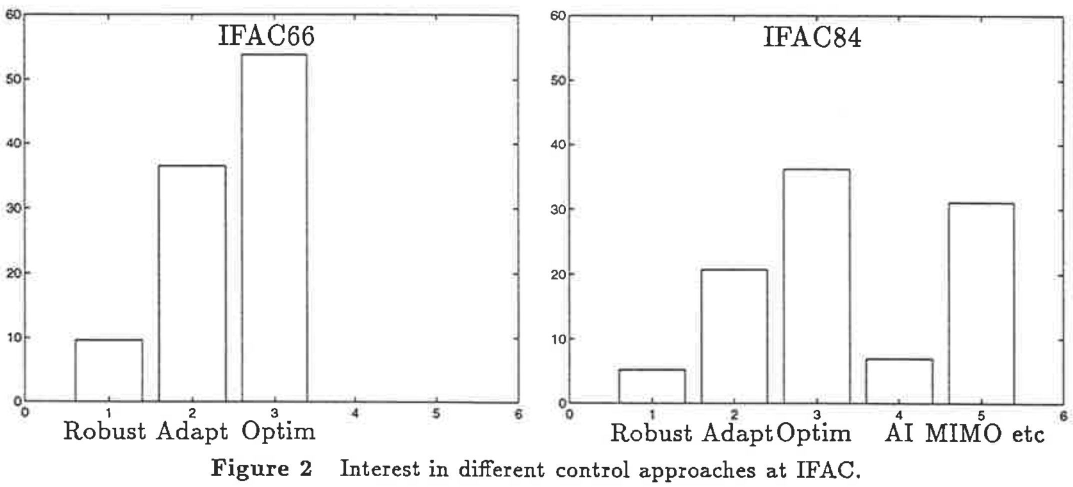


Figure 2 Interest in different control approaches at IFAC.

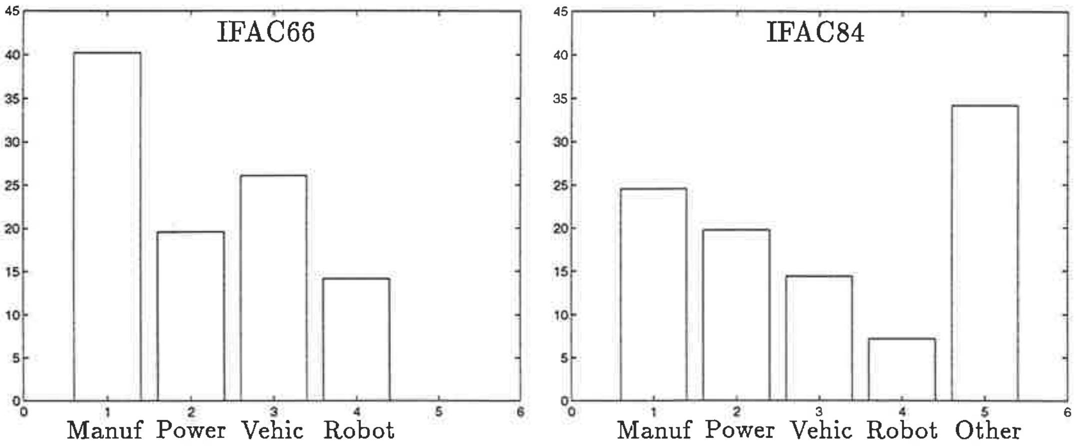


Figure 3 Interest in different applications at IFAC.

largest part of the application papers. Examples of new areas are medical and water resource applications.

The interest within the application areas has also shifted over the years. Manufacturing meant in 1966 almost exclusively process control, chemical, steel, paper etc. In 1984 the manufacturing applications are more diverse with a lot of interest shifted into assembling industry and flexible manufacturing. Robotic applications has went from motor and velocity control to for example path planning and manipulator control. In vehicular systems much more attention in 1984 is on road transportation compared to 1966 when almost all papers dealt with aerospace applications.

Comparisons with CDC and ACC

We can not do temporal comparisons with CDC and ACC since they did not start until the 70'ies. But we can compare the IFAC figures with their 'specialties', i. e., control theory at CDC and applications at ACC.

At CDC there is much less interest in optimal control and it is more or less focussed on adaptive control. There is also a lot of interest in AI, fuzzy control and neural networks, and in control of systems described by partial differential equations, PDEs. The interest in PDEs is also very pronounced in the systems sessions at CDC, see Appendix B. Application sessions at ACC focus a lot on process control, flight control and robotics. The obscure applications at IFAC don't even exist at ACC.

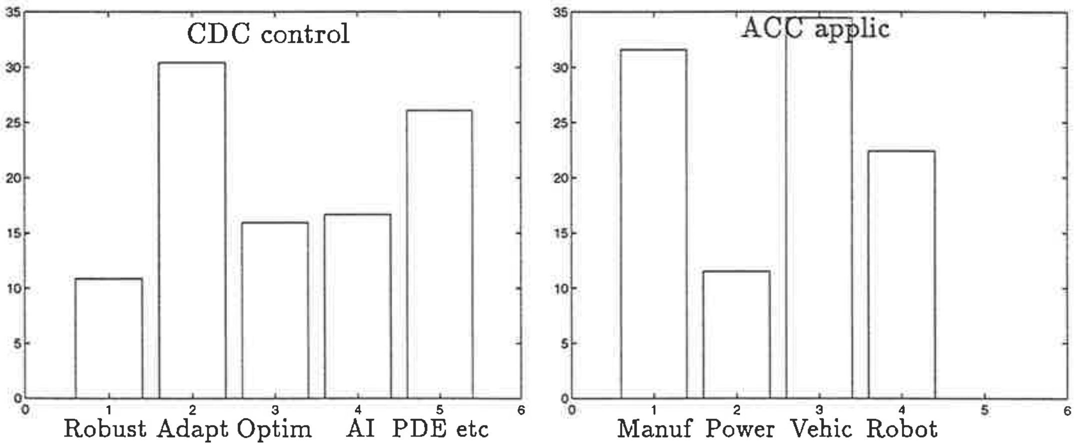


Figure 4 Control approaches at CDC and applications at ACC.

A. Detailed subject data

IFAC 66		
System Theory		**76**
Linear Systems	21	
Nonlinear Systems	21	
Discrete Time		
Discrete Event	21	
Distributed Parameter		
Stochastic	13	
Modeling and Identification		**11**
Modelling and Model Reduction		
Identification and Estimation	11	
Control Design Methods		**52**
Linear		
Robust	5	
Adaptive	19	
Optimal	28	
Stochastic		
Nonlinear		
Decentralized		
AI		
Computers, Hardware, and Algorithms		**32**
Real-Time Control		
CACSD and Simulation Tool		
Algorithms and Numerics	7	
Hardware	25	
Other		
Applications		**96**
Industrial Process Control	37	
Power Generation and Distribution	18	
Aerospace and Vehicular Control	24	
Robotic Control	13	
Biological	4	
Social and Economic		
Education		
Signal and Image Processing		
High-Level Control		**5**
Planning and Scheduling	5	
Fault Detection and Diagnosis		
Man-machine		
Other		
		272

IFAC 84

System Theory	36	**65**
Linear Systems	12	
Nonlinear Systems	11	
Discrete Time		
Discrete Event		
Distributed Parameter	6	
Stochastic		
Modeling and Identification		**66**
Modelling and Model Reduction	12	
Identification and Estimation	54	
Control Design Methods		**116**
Linear	24	
Robust	6	
Adaptive	24	
Optimal	42	
Stochastic		
Nonlinear		
Decentralized	12	
AI	8	
Computers, Hardware, and Algorithms	18	**62**
Real-Time Control	9	
CACSD and Simulation Tool	29	
Algorithms and Numerics	6	
Hardware		
Applications	42	**206**
Industrial Process Control	41	
Power Generation and Distribution	33	
Aerospace and Vehicular Control	24	
Robotic Control	12	
Biological	33	
Social and Economic	9	
Education	6	
Signal and Image Processing	6	
High-Level Control		**53**
Planning and Scheduling	11	
Fault Detection and Diagnosis	30	
Man-machine	12	
Other		**3**
		571

ACC 84		
System Theory		**22**
Linear Systems	8	
Nonlinear Systems		
Discrete Time	3	
Discrete Event		
Distributed Parameter		
Stochastic		
Modeling and Identification		**36**
Modelling and Model Reduction	27	
Identification and Estimation	9	
Control Design Methods	12	**103**
Linear	18	
Robust	8	
Adaptive	29	
Optimal	6	
Stochastic	6	
Nonlinear	6	
Decentralized		
AI	18	
Computers, Hardware, and Algorithms		**27**
Real-Time Control		
CACSD and Simulation Tool	12	
Algorithms and Numerics		
Hardware	15	
Applications		**187**
Industrial Process Control	55	
Power Generation and Distribution	20	
Aerospace and Vehicular Control	60	
Robotic Control	39	
Biological		
Social and Economic		
Education		
Signal and Image Processing	13	
High-Level Control		**9**
Planning and Scheduling		
Fault Detection and Diagnosis	9	
Man-machine		
		384

CDC 84

System Theory		**149**
Linear Systems	37	
Nonlinear Systems	32	
Discrete Time	18	
Discrete Event	9	
Distributed Parameter	40	
Stochastic	13	
Modeling and Identification		**41**
Modelling and Model Reduction	7	
Identification and Estimation	34	
Control Design Methods		**138**
Linear	8	
Robust	15	
Adaptive	42	
Optimal	22	
Stochastic		
Nonlinear	28	
Decentralized		
AI	23	
Computers, Hardware, and Algorithms	11	**11**
Real-Time Control		
CACSD and Simulation Tool		
Algorithms and Numerics		
Hardware		
Applications		**66**
Industrial Process Control	5	
Power Generation and Distribution	8	
Aerospace and Vehicular Control	13	
Robotic Control	24	
Biological		
Social and Economic		
Education		
Signal and Image Processing	16	
High-Level Control		**27**
Planning and Scheduling	5	
Fault Detection and Diagnosis	22	
Man-machine		
Other		**14**
		446

Control Conferences 1969 and 1987

Mattias Grundelius and Karl Henrik Johansson

May 1996

This is a collection of statistics from four control conference proceedings. The captured conferences are two American, ACC 1969 and CDC 1987, and two hosted by IFAC in 1969 and 1987. By dividing the sessions into six main topics, the evolvement of the control field under almost two decades is illustrated. The results can be summarized in the following items.

- The control field is growing. ACC 1969 and IFAC 1969 had 37 + 58 sessions, while CDC 1987 and IFAC 1987 had 76 + 137 sessions.
- Research in High-Level Control has been born within the last two decades. Scheduling, fault detection, and diagnosis have become an area in the control field.
- The number of sessions in control hardwares and algorithms have diminished considerable.
- Robust control and AI are two concepts used in control design 1987 but not in 1969.
- Applications are discussed more at IFAC congresses than at ACC and CDC. This includes industrial applications as well as applications in social and economic sciences.

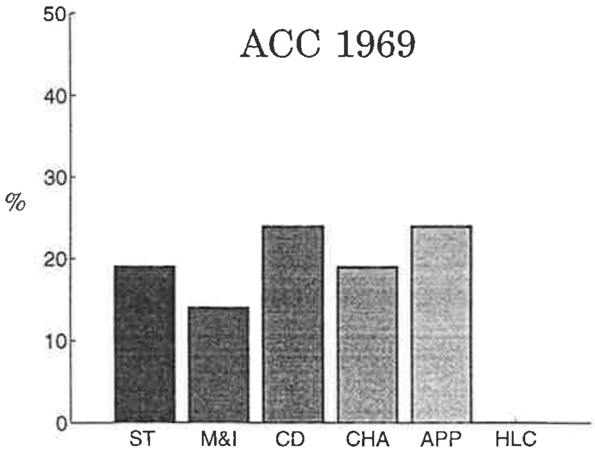
Next each conference is treated separately and histogram showing the distribution of the following six main topics are presented.

ST	System Theory
M&I	Modeling and Identification
CD	Controller Design Methods
CHA	Computers, Hardware and Algorithms
APP	Applications
HLC	High-Level Control

These topics are further divided into three to eight subtopics and summarized in tabular form.

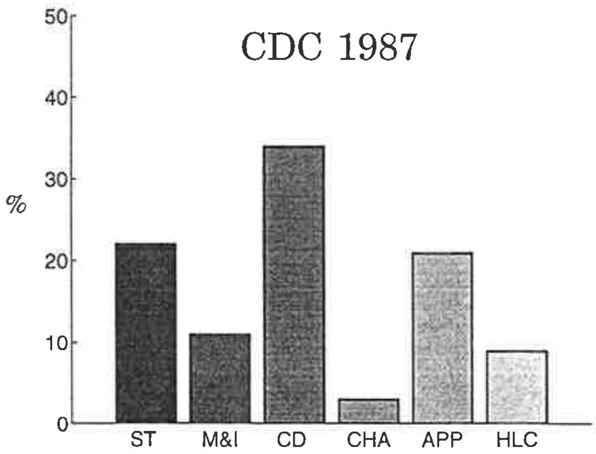
ACC 1969

1969 American Control Conference was held in Boulder near Denver. The conference included 37 ordinary sessions and 5 plenary talks. To be noted is that there were three sessions on fluid circuits and that all plenaries were on applications.



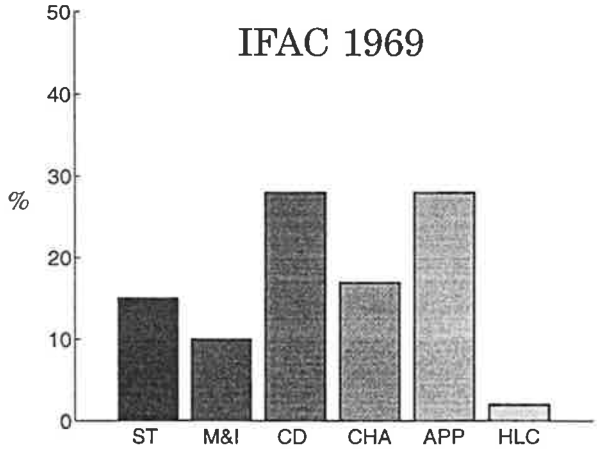
CDC 1987

1987 Conference on Decision and Control was held in Los Angeles. The conference included 74 ordinary sessions and the two plenary sessions "Problems with implementation of classical control approaches" by S. C. Jacobsen and "Paradigms and puzzles in modelling dynamical systems" by J. C. Willems. To be noted is that there were one session on SDI battle management and one on Kharitonov's Theorem.



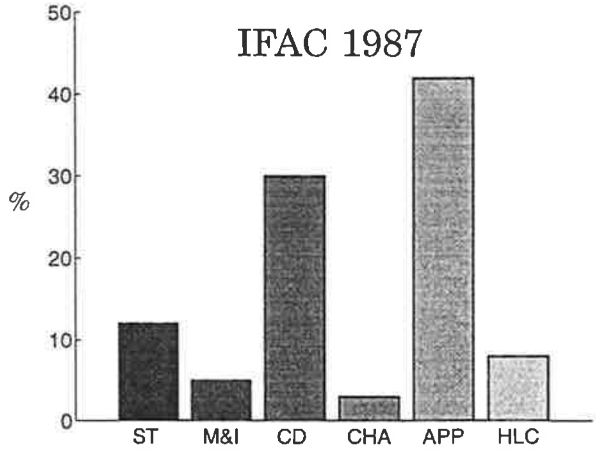
IFAC 1969

1969 International Federation of Automatic Control World Congress was held in Warzaw. The congress included 51 ordinary sessions together with presentation of 7 survey papers. To be noted is that there was one session on fluidics.



IFAC 1987

1987 International Federation of Automatic Control World Congress was held in Munich. The congress included 122 ordinary sessions and 15 discussion sessions. Added to this five plenary papers were presented: one theoretical, three on industrial applications, and one on information technology in control.



ACC 1969

System Theory		**7**
General		
Linear Systems	2	
Nonlinear Systems	2	
Discrete Time		
Discrete Event		
Distributed Parameter	3	
Stochastic		
Modeling and Identification		**5**
Modeling and Model Reduction	1	
Identification and Estimation	4	
Control Design Methods		**9**
Linear		
Robust		
Adaptive	1	
Optimal	5	
Stochastic	2	
Nonlinear		
Decentralized	1	
AI		
Computers, Hardware, and Algorithms		**7**
Real-Time Control		
CACSD and Simulation Tools	1	
Algorithms and Numerics	3	
Hardware	3	
Applications		**9**
Industrial Process Control	2	
Power Generation and Distribution	3	
Aerospace and Vehicular Control	2	
Robotic Control		
Biological	1	
Social and Economic		
Education	1	
High-Level Control		**0**
Planning and Scheduling		
Fault Detection and Diagnosis		
Man-Machine		
		37

CDC 1987

System Theory		**17**
General	2	
Linear Systems	2	
Nonlinear Systems	4	
Discrete Time	2	
Discrete Event	2	
Distributed Parameter	4	
Stochastic	1	
Modeling and Identification		**8**
Modeling and Model Reduction	3	
Identification and Estimation	5	
Control Design Methods		**26**
Linear	1	
Robust	4	
Adaptive	6	
Optimal	6	
Stochastic	3	
Nonlinear	2	
Decentralized	2	
AI	2	
Computers, Hardware, and Algorithms		**2**
Real-Time Control		
CACSD and Simulation Tools		
Algorithms and Numerics	2	
Hardware		
Applications		**16**
Industrial Process Control		
Power Generation and Distribution	2	
Aerospace and Vehicular Control	2	
Robotic Control	7	
Biological		
Social and Economic	3	
Education		
Signal and Image Processing	2	
High-Level Control		**7**
Planning and Scheduling	5	
Fault Detection and Diagnosis	2	
Man-Machine		
		76

IFAC 1969

System Theory		**9**
General	1	
Linear Systems	4	
Nonlinear Systems	2	
Discrete Time		
Discrete Event	1	
Distributed Parameter		
Stochastic	1	
Modeling and Identification		**6**
Modeling and Model Reduction		
Identification and Estimation	6	
Control Design Methods		**16**
Linear	1	
Robust		
Adaptive	4	
Optimal	6	
Stochastic	1	
Nonlinear	1	
Decentralized	3	
AI		
Computers, Hardware, and Algorithms		**10**
Real-Time Control		
CACSD and Simulation Tools		
Algorithms and Numerics	4	
Hardware	6	
Applications		**16**
Industrial Process Control	6	
Power Generation and Distribution	4	
Aerospace and Vehicular Control	4	
Robotic Control		
Biological	1	
Social and Economic	1	
Education		
Signal and Image Processing		
High-Level Control		**1**
Planning and Scheduling		
Fault Detection and Diagnosis	1	
Man-Machine		
		58

IFAC 1987

System Theory		**17**
General		
Linear Systems	7	
Nonlinear Systems	2	
Discrete Time	5	
Discrete Event		
Distributed Parameter	3	
Stochastic		
Modeling and Identification		**7**
Modeling and Model Reduction	1	
Identification and Estimation	6	
Control Design Methods		**41**
Linear	3	
Robust	4	
Adaptive	11	
Optimal	1	
Stochastic	3	
Nonlinear	8	
Decentralized	6	
AI	5	
Computers, Hardware, and Algorithms		**4**
Real-Time Control		
CACSD and Simulation Tools		
Algorithms and Numerics	3	
Hardware	1	
Applications		**57**
Industrial Process Control	12	
Power Generation and Distribution	9	
Aerospace and Vehicular Control	14	
Robotic Control	1	
Biological	5	
Social and Economic	14	
Education	2	
Signal and Image Processing		
High-Level Control		**11**
Planning and Scheduling	4	
Fault Detection and Diagnosis	3	
Man-Machine	4	
		137

Trends in Automatic Control – changes from 1972 to 1990

Mats Åkesson
Mikael Johansson

May 21, 1996

The following pages is an account of a project in the course "History of Automatic Control". The purpose of the project is to give a perspective on the development of Automatic Control by studying the themes of the sessions at the major control conferences.

In order to get some kind of measure of the changes, the conference sessions have been classified under various subjects. It turned out to be quite hard to come up with a classification system that gives a brief overview of the conference themes while being fair to most areas of control. For reference, we include an alternative classification system from IEEE Control Systems October 1995. The statistics shown in appendix are based on proceedings from ACC (1972, 1990), IFAC (1972, 1990) and CDC (1990).

In many areas, the changes from 1972 to 1990 are minor and appears to be natural developments of the field. By large, however, the conference proceedings display a shifted focus; from hardware and applications to control theory and mathematics.

The largest increase of interest seems to have been in the area of "Robust Control". Triggered by the classical paper of Doyle in 1977 this mathematical direction have become well established in the control community. From 1990, the branch of Robust Control have continued to grow. At the IFAC 1996 conference, more than 7 percent of the sessions will be devoted to this subject.

The decline of the percentage of sessions devoted to more practical issues listed under "Applications" and "Computers, Algorithms and Hardware" is also noteworthy. An explanation for this could be that some of the topics are on the borderline to other disciplines or that they have developed to disciplines of their own. Typical examples are "Real-time Control" and "Simulation".

Except for the more expected contributions in the fields of control theory and industrial applications, skimming through the proceedings also reveals more surprising ones. These are found in diverse areas and range from theory of peace-making and social sciences to modeling and control of fish behavior. But, as a former PhD student Anders Hansson put it: "It's a general theory".

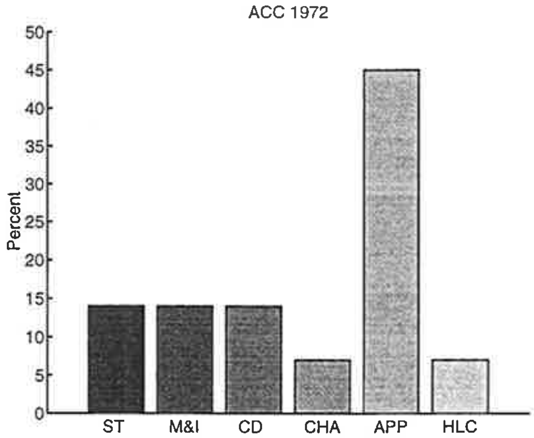
A. Statistics

Legend

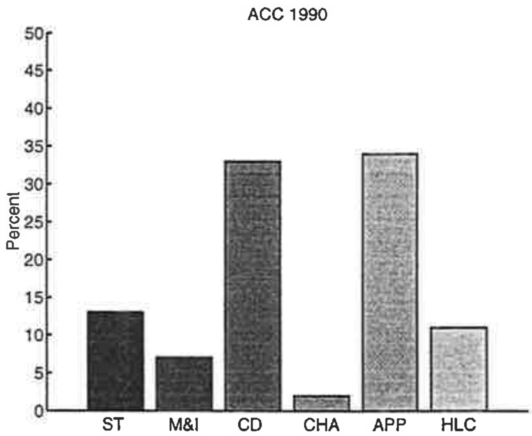
ST	System Theory
M&I	Modelling and Identification
CD	Controller Design Methods
CHA	Computers, Hardware and Algorithms
APP	Applications
HLC	High-level Control

For detailed statistics on session subjects see appendix B.

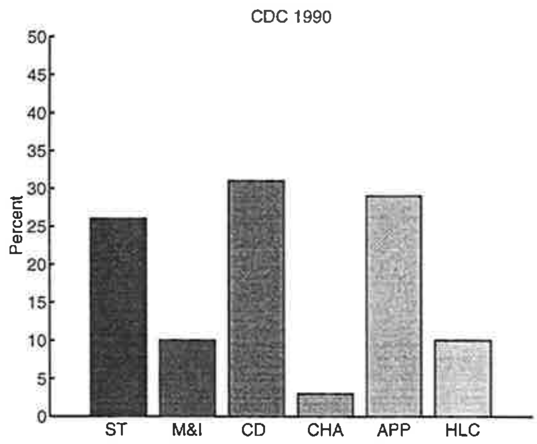
ACC 1972



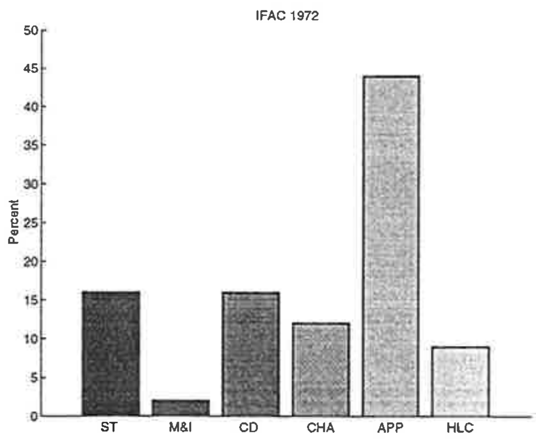
ACC 1990



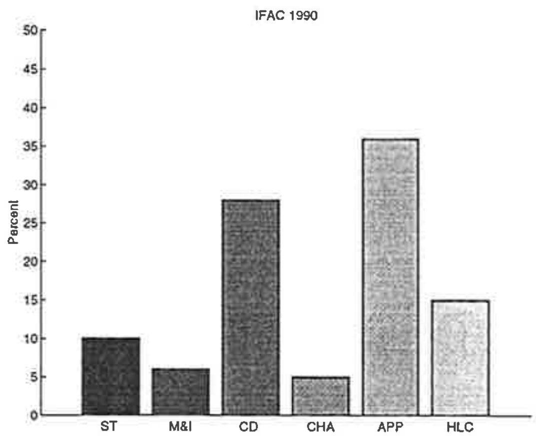
CDC 1990



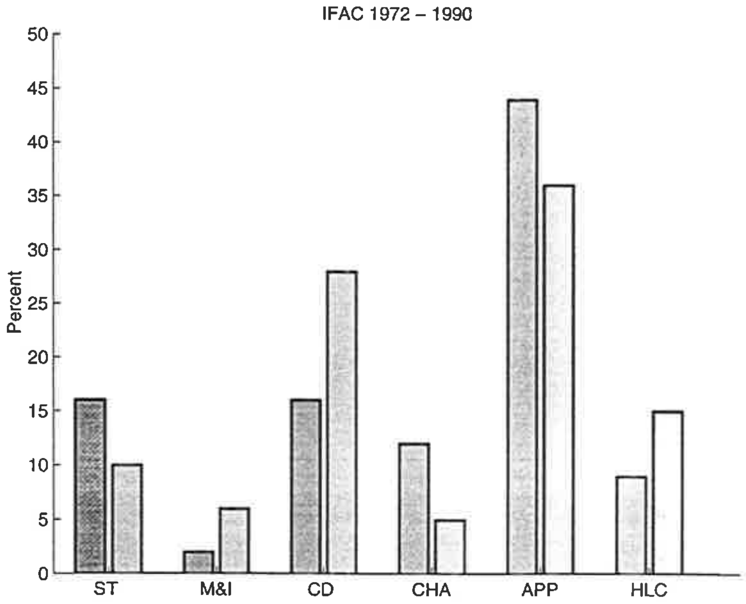
IFAC 1972



IFAC 1990

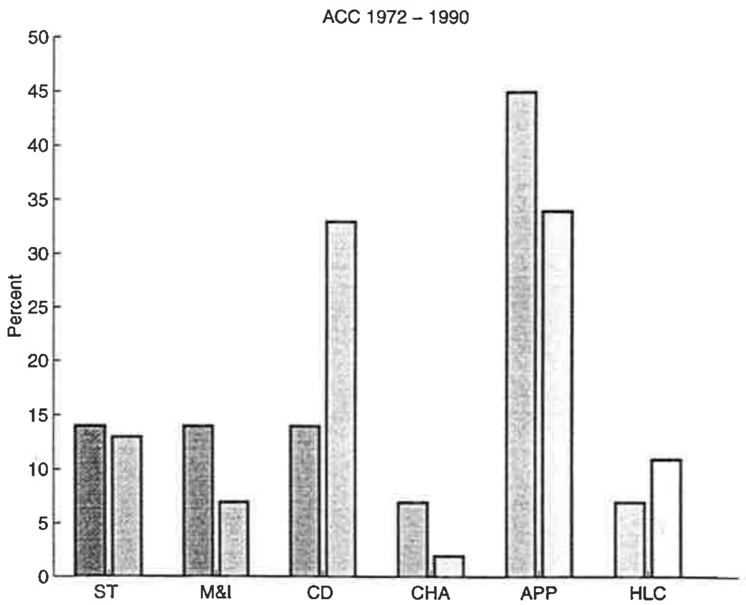


IFAC 1972 and 1990



Changes from 1972 to 1990. The left bar in each pair showing statistics from 1972.

ACC 1972 and 1990



Changes from 1972 to 1990. The left bar in each pair showing statistics from 1972.

=======
IFAC '72
=======

System Theory		16 %
o Linear Systems	(3/7)	
o Nonlinear Systems	(1/7)	
o Discrete Time	(2/7)	
o Discrete Event		
o Distributed Parameter	(1/7)	
o Stability		
Modelling and Identification		2 %
o Identification and model reduction	(0.5/1)	
o Estimation and Filtering	(0.5/1)	
Controller Design Methods		16 %
o Robust		
o Adaptive	(2/7)	
o Optimal	(2/7)	
o Stochastic	(1/7)	
o Nonlinear		
o AI		
o Other	(2/7)	
Computers, Hardware and Algorithms		12 %
o Real-Time Control		
o CACSD and Simulation Tools		
o Algorithms and Numerics	(1/5)	
o Hardware	(4/5)	
Applications		44 %
o Industrial Process Control	(9/19)	
o Power Generation and Distribution	(3/19)	
o Aerospace and Vehicular Control	(4/19)	
o Robotic Control		
o Biological	(1/19)	
o Social and Economic	(2/19)	
High Level Control		9 %
o Planning and Scheduling	(2/4)	
o Structuring and Decentralized Control	(2/4)	
o Monitoring, Fault Detection and Diagnosis		

The statistics where computed based on 43 sessions.

========
IFAC '90
========

System Theory		10 %
o Linear Systems	(4/12)	
o Nonlinear Systems	(2/12)	
o Discrete Time		
o Discrete Event	(2/12)	
o Distributed Parameter	(1/12)	
o Stability	(3/12)	
Modelling and Identification		6 %
o Identification and model reduction	(7/12)	
o Estimation and Filtering		
Controller Design Methods		28 %
o Robust	(6/12)	
o Adaptive	(9/12)	
o Optimal	(3/12)	
o Stochastic	(1/12)	
o Nonlinear	(3/12)	
o AI	(10/12)	
o Other	(1/12)	
Computers and Algorithms		5 %
o Real-Time Control	(3/6)	
o CACSD and Simulation Tools	(3/6)	
o Algorithms and Numerics		
o Hardware		
Applications		36 %
o Industrial Process Control	(9/42)	
o Power Generation and Distribution	(6/42)	
o Aerospace and Vehicular Control	(7/42)	
o Robotic Control	(5/42)	
o Biological	(5/42)	
o Social and Economic	(10/42)	
High Level Control		15 %
o Planning and Scheduling	(8/17)	
o Structuring and Decentralized Control	(6/17)	
o Monitoring, Fault Detection and Diagnosis	(3/17)	

The statistics where computed based on 117 sessions.

=======
ACC '72
=======

System Theory		14 %
o Linear Systems	(2/4)	
o Nonlinear Systems		
o Discrete Time		
o Discrete Event		
o Distributed Parameter	(1/4)	
o Stability	(1/4)	
Modelling and Identification		14 %
o Identification and model reduction	(4/4)	
o Estimation and Filtering		
Controller Design Methods		14 %
o Robust		
o Adaptive	(1/4)	
o Optimal	(2/4)	
o Stochastic	(1/4)	
o Nonlinear		
o AI		
o Other		
Computers and Algorithms		7 %
o Real-Time Control		
o CACSD and Simulation Tools	(1/2)	
o Algorithms and Numerics	(1/2)	
o Hardware		
Applications		45 %
o Industrial Process Control	(1/13)	
o Power Generation and Distribution	(1/13)	
o Aerospace and Vehicular Control	(6/13)	
o Robotic Control		
o Biological	(3/13)	
o Social and Economic	(2/13)	
High Level Control		7 %
o Planning and Scheduling	(1/2)	
o Structuring and Decentralized Control	(1/2)	
o Monitoring, Fault Detection and Diagnosis		

The statistics where computed based on 29 sessions.

ACC'90

System Theory		13 %
o Linear Systems	(2/11)	
o Nonlinear Systems	(2/11)	
o Discrete Time	(2/11)	
o Discrete Event	(2/11)	
o Distributed Parameter	(1/11)	
o Stability	(2/11)	
Modelling and Identification		7 %
o Identification and model reduction	(6/6)	
o Estimation and Filtering		
Controller Design Methods		33 %
o Robust	(9/27)	
o Adaptive	(5/27)	
o Optimal	(1/27)	
o Stochastic	(1/27)	
o Nonlinear	(3/27)	
o AI	(7/27)	
o Other	(1/27)	
Computers and Algorithms		2 %
o Real-Time Control		
o CACSD and Simulation Tools		
o Algorithms and Numerics	(2/2)	
o Hardware		
Applications		34 %
o Industrial Process Control	(6/28)	
o Power Generation and Distribution		
o Aerospace and Vehicular Control	(10/28)	
o Robotic Control	(9/28)	
o Biological	(3/28)	
o Social and Economic		
High Level Control		11 %
o Planning and Scheduling	(6/9)	
o Structuring and Decentralized Control	(2/9)	
o Monitoring, Fault Detection and Diagnosis	(1/9)	

The statistics where computed based on 83 sessions.

=======
CDC '90
=======

System Theory		26 %
o Linear Systems	(10/34)	
o Nonlinear Systems	(4/34)	
o Discrete Time	(3/34)	
o Discrete Event	(5/34)	
o Distributed Parameter	(8/34)	
o Stability	(4/34)	
Modelling and Identification		10 %
o Identification and model reduction	(6/13)	
o Estimation and Filtering	(7/13)	
Controller Design Methods		31 %
o Robust	(11/40)	
o Adaptive	(7/40)	
o Optimal	(3/40)	
o Stochastic	(6/40)	
o Nonlinear	(5/40)	
o AI	(7/40)	
o Other		
Computers, Hardware and Algorithms		3 %
o Real-Time Control		
o CACSD and Simulation Tools		
o Algorithms and Numerics	(4/4))	
o Hardware		
Applications		29 %
o Industrial Process Control	(5/29)	
o Power Generation and Distribution	(3/29)	
o Aerospace and Vehicular Control	(9/29)	
o Robotic Control	(12/29)	
o Biological		
o Social and Economic		
High Level Control		10 %
o Planning and Scheduling	(7/10)	
o Structuring and Decentralized Control	(2/10)	
o Monitoring, Fault Detection and Diagnosis	(1/10)	

The statistics where computed based on 130 sessions.

Control Conferences 1975 and 1993

Johan Eker, Erik Möllerstedt and Tsao Yong

August 1996

This is a collection of statistics from six control conference proceedings. The captured conferences are JACC 1974, ACC 1993, CDC 1975 and 1993, and the IFAC World Congresses in 1975 and 1993.

Each conference is treated separately and histograms showing the distribution of the following six main topics are presented.

ST	System Theory
M&I	Modeling and Identification
CD	Controller Design Methods
CHA	Computers, Hardware and Algorithms
APP	Applications
HLC	High-Level Control

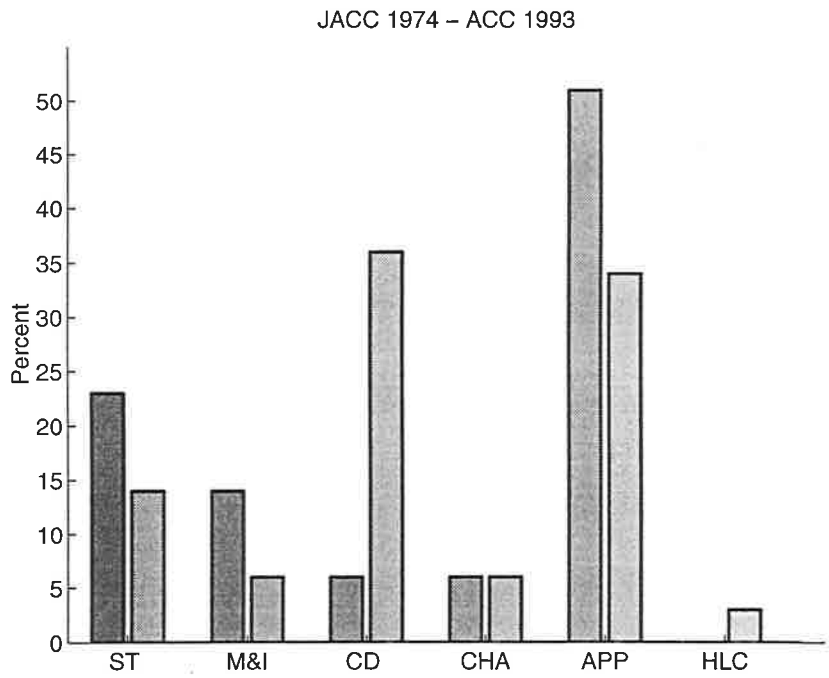
These topics are further divided into three to eight subtopics and summarized in tabular form.

JACC 1974

The 1974 Joint American Control Conference was held in Austin, Texas, and the host was the American Institute of Chemical Engineers. This may explain the somewhat odd sessions like "Modelling and Control of Insect Population" and "Research Management for Crop Grows Systems" with two papers on cotton growth. In total there were 35 sessions.

ACC 1993

The 1993 American Control Conference was held in San Fransisco. Significant, when comparing with the 1974 JACC, was the interest for robust, adaptive and non-linear control and robotics. More than 10 sessions were dedicated to each of these topics. Biological, Social and Economical topics, however, had no sessions at all. The total number of sessions was 126.

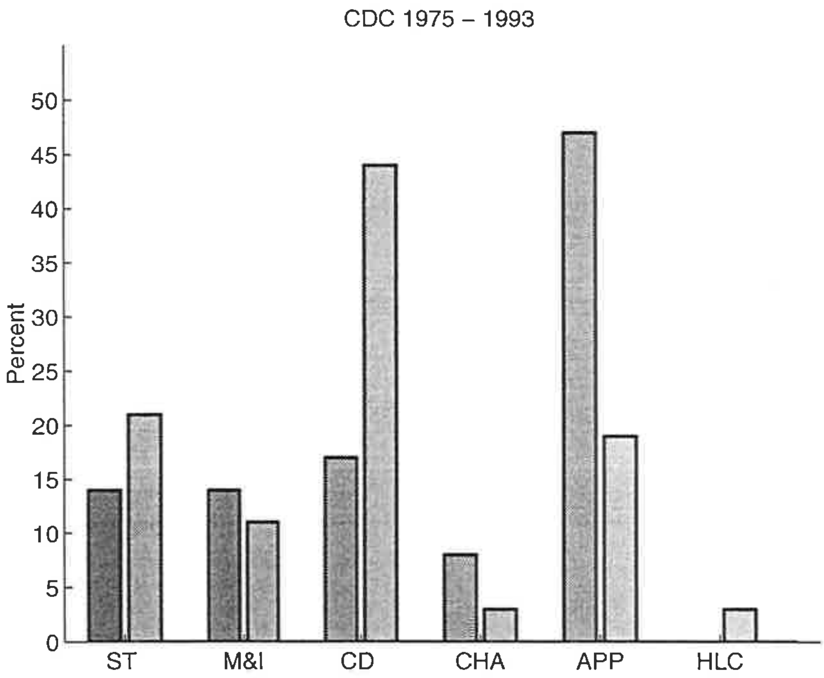


CDC 1975

The 1975 Conference on Decision and Control was held in Huston, Texas. It was held by the IEEE Control System Society in cooperation with the Society for Industrial and Applied Mathematics. The Conference included 36 sessions. Sessions that should be pointed out were two on Seismic Data Processing and Interpretation, two on Application of Remotely Sensed Digital Imagery to Mineral and Petroleum Exploration. Popular were also sessions on estimation and identification.

CDC 1993

The 1993 Conference on Decision and Control was held in San Antonio, Texas. It was held by the IEEE Control System Society in cooperation with the Society for Industrial and Applied Mathematics, SIAM, and Operations Research Society of America, ORSA. The total number of sessions was 112. Two of the three plenary sessions were on semiconductor manufacturing – a new application area for control?

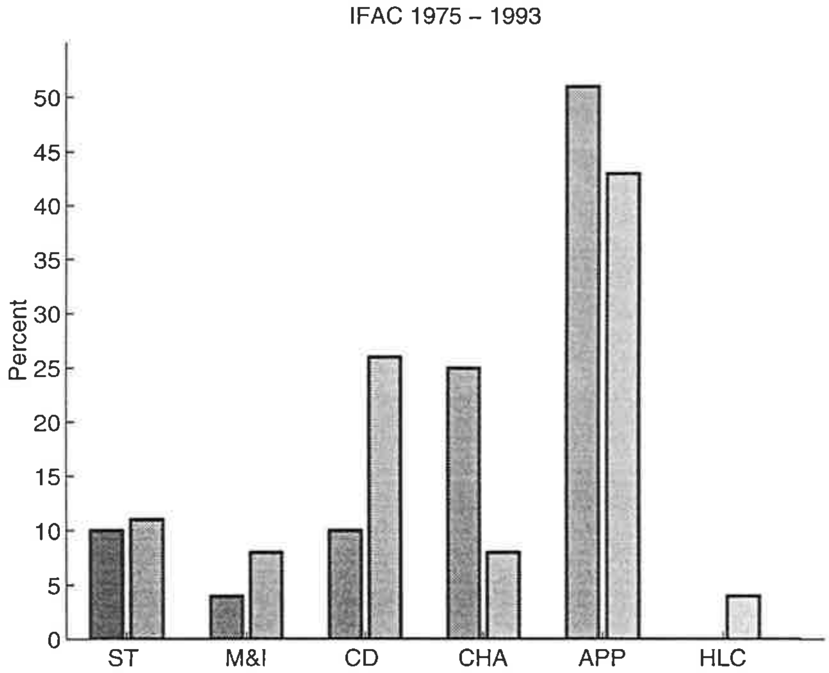


IFAC 75

The 6th IFAC World Conference was held in Cambridge/Boston, Massachusetts, U.S.A., August 24-30, 1975. To be noted is the focus on implementations and applications.

IFAC 93

The 12th IFAC World Congress was held in Darling Harbour in Sydney, Australia, July 18-23 1993. Compared to the IFAC conference 1973 the biggest differences are that more emphasis is put on control design and high-level control.



JACC 1974

System Theory		**8**
General	5	
Linear Systems	1	
Nonlinear Systems		
Discrete Time		
Discrete Event		
Distributed Parameter	1	
Stochastic	1	
Modeling and Identification		**5**
Modelling and Model Reduction	1	
Identification and Estimation	4	
Control Design Methods		**2**
Linear		
Robust		
Adaptive	1	
Optimal	1	
Stochastic		
Nonlinear		
Decentralized		
AI		
Computers, Hardware, and Algorithms		**2**
Real-Time Control		
CACSD and Simulation Tool		
Algorithms and Numerics	1	
Hardware	1	
Applications		**18**
General	2	
Industrial Process Control	1	
Power Generation and Distribution	1	
Aerospace and Vehicular Control	5	
Robotic Control		
Biological	3	
Social and Economic	4	
Education	1	
Signal and Image Processing	1	
High-Level Control		**0**
Planning and Scheduling		
Fault Detection and Diagnosis		
Man-machine		
		137

ACC 1993

System Theory		**20**
General	3	
Linear Systems	4	
Nonlinear Systems	4	
Discrete Time	3	
Discrete Event	3	
Distributed Parameter	1	
Stochastic	2	
Modeling and Identification		**9**
Modelling and Model Reduction	3	
Identification and Estimation	6	
Control Design Methods		**51**
Linear		
Robust	15	
Adaptive	10	
Optimal	3	
Stochastic	2	
Nonlinear	16	
Decentralized	2	
AI	3	
Computers, Hardware, and Algorithms		**8**
Real-Time Control		
CACSD and Simulation Tool	2	
Algorithms and Numerics	6	
Hardware		
Applications		**49**
General		
Industrial Process Control	5	
Power Generation and Distribution	1	
Aerospace and Vehicular Control	10	
Robotic Control	13	
Biological		
Social and Economic		
Education	3	
Signal and Image Processing	2	
High-Level Control		**4**
Planning and Scheduling		
Fault Detection and Diagnosis	4	
Man-machine		
		137

CDC 1975

System Theory		**5**
General	2	
Linear Systems	2	
Nonlinear Systems	1	
Discrete Time		
Discrete Event		
Distributed Parameter		
Stochastic		
Modeling and Identification		**5**
Modelling and Model Reduction		
Identification and Estimation	5	
Control Design Methods		**6**
Linear		
Robust		
Adaptive	1	
Optimal	3	
Stochastic		
Nonlinear		
Decentralized	2	
AI		
Computers, Hardware, and Algorithms		**3**
Real-Time Control	1	
CACSD and Simulation Tool		
Algorithms and Numerics	2	
Hardware		
Applications		**17**
General	2	
Industrial Process Control		
Power Generation and Distribution	2	
Aerospace and Vehicular Control	3	
Robotic Control	1	
Biological	2	
Social and Economic	2	
Education	1	
Signal and Image Processing	4	
High-Level Control		**0**
Planning and Scheduling		
Fault Detection and Diagnosis		
Man-machine		
		137

CDC 1993

System Theory		**23**
General	5	
Linear Systems	3	
Nonlinear Systems	4	
Discrete Time	3	
Discrete Event	5	
Distributed Parameter	2	
Stochastic	1	
Modeling and Identification		**12**
Modelling and Model Reduction	3	
Identification and Estimation	9	
Control Design Methods		**47**
Linear	3	
Robust	12	
Adaptive	11	
Optimal	3	
Stochastic	1	
Nonlinear	8	
Decentralized	1	
AI	8	
Computers, Hardware, and Algorithms		**3**
Real-Time Control		
CACSD and Simulation Tool		
Algorithms and Numerics	3	
Hardware		
Applications		**20**
General	3	
Industrial Process Control	2	
Power Generation and Distribution	2	
Aerospace and Vehicular Control	4	
Robotic Control	7	
Biological		
Social and Economic		
Education		
Signal and Image Processing	2	
High-Level Control		**3**
Planning and Scheduling	1	
Fault Detection and Diagnosis	2	
Man-machine		
		137

IFAC 1975

System Theory		**5**
General	2	
Linear Systems	1	
Nonlinear Systems		
Discrete Time	1	
Discrete Event		
Distributed Parameter	1	
Stochastic		
Modeling and Identification		**2**
Modelling and Model Reduction		
Identification and Estimation	2	
Control Design Methods		**5**
Linear		
Robust		
Adaptive	2	
Optimal	1	
Stochastic	1	
Nonlinear	1	
Decentralized		
AI		
Computers, Hardware, and Algorithms		**13**
Real-Time Control	4	
CACSD and Simulation Tool	2	
Algorithms and Numerics	2	
Hardware	5	
Applications		**26**
General		
Industrial Process Control	7	
Power Generation and Distribution	4	
Aerospace and Vehicular Control	6	
Robotic Control		
Biological	2	
Social and Economic	6	
Education		
Signal and Image Processing		
High-Level Control		**0**
Planning and Scheduling		
Fault Detection and Diagnosis		
Man-machine		
		137

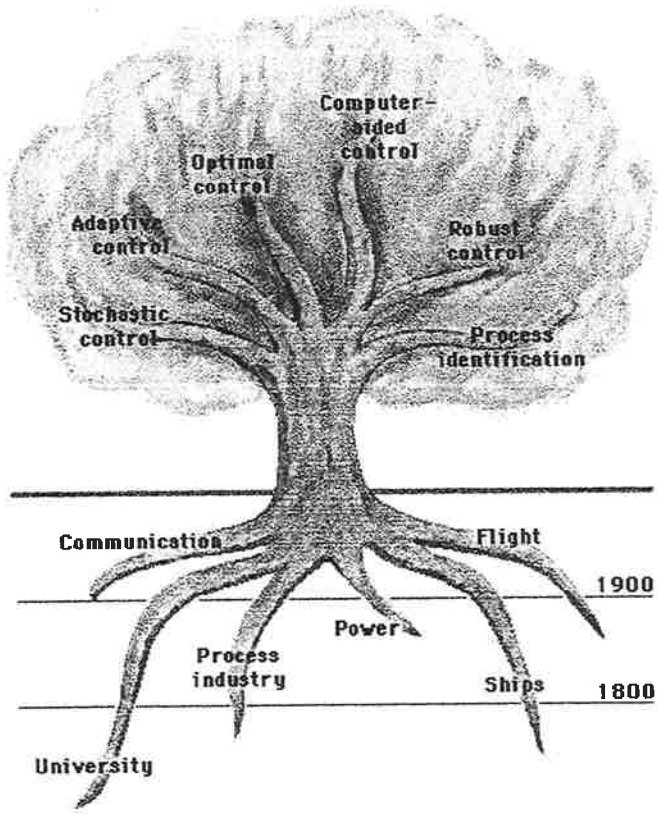
IFAC 1993

System Theory		**20**
General	11	
Linear Systems	3	
Nonlinear Systems	2	
Discrete Time		
Discrete Event	3	
Distributed Parameter	1	
Stochastic		
Modeling and Identification		**14**
Modelling and Model Reduction	5	
Identification and Estimation	9	
Control Design Methods		**48**
Linear	4	
Robust	17	
Adaptive	6	
Optimal	1	
Stochastic	2	
Nonlinear	8	
Decentralized		
AI	10	
Computers, Hardware, and Algorithms		**15**
Real-Time Control	6	
CACSD and Simulation Tool	2	
Algorithms and Numerics	4	
Hardware	3	
Applications		**78**
General	8	
Industrial Process Control	16	
Power Generation and Distribution	7	
Aerospace and Vehicular Control	13	
Robotic Control	14	
Biological	9	
Social and Economic	6	
Education	2	
Signal and Image Processing	3	
High-Level Control		**7**
Planning and Scheduling	2	
Fault Detection and Diagnosis	5	
Man-machine		
		137

The Control Tree

Charlotta Johnsson and Hélène Panagopoulos

History of Automatic Control



Stochastic Control

With stochastic control one mean the control of the behavior of physical processes subject to random disturbances and random measurement errors. The control problem is that of determining inputs to a process in order to achieve desired goals in spite of the random disturbances which are present.

Adaptive Control

Control in which automatic and continual measurement of the process to be controlled is used as a basis for the automatic and continuing self-design of the control system.

Optimal Control

Optimal Control is one particular branch of modern control that sets out to provide analytical designs of a specially appealing type. The system which is the end result of an optimal design is not supposed merely to be stable, have a certain bandwidth or satisfy any one of the desirable constraints associated with classical control, but it is supposed to be the best possible system of a particular type - hence, the word optimal. If it is both optimal and possesses a number of the properties that classical control suggests are desirable, so much better.

Computer Aided Control

From the earliest days of the use of computers in engineering, the design of control systems has made heavy demands on such facilities because of its algorithmic-intensive nature. Interactive computing has been an essential ingredient for encouraging creativity in the design of real-time feedback systems.

Robust Control

Controllers are usually designed to stabilize and control a model of a real system. Stability does however not necessarily follow when the controllers is used on the real process. This due to inevitable uncertainty incurred by approximations and unmodelled dynamics, parameter variation or contamination by noise. This situation has led to the design of controllers which are robust against such uncertainties and the problem is referred to as the robustness problem.

Process Identification

Process Identification is the field of modeling of dynamic systems from experimental data. Such mathematical models can be of various kind, but differential equations and difference equations are perhaps the most typical examples. There are many areas in the field of control and signal processing where it is important to have mathematical models. In many cases the processes are themselves so complex that it is not possible to get good models using only physical insight, In such cases the user is faced to use identification techniques.

Telecommunication

Post-script file

The AT\&T company formed, in 1907, an industrial research laboratory. This as parts of its strategy of controlling all American telecommunications. For telecommunication amplification of electrical signals, representing the speech pattern, were vital.The first amplifiers used were electro-mechanical devices. Although the electro-mechanical repeaters had many practical limitations, an open-wire line was reached in 1911. The east-coast of the USA was linked to Denver, Colorado and conversation was possible.

H.D. Arnold investigated the potential applications of the vacuum tube, as part of his research in wireless systems. He recognized its importance for wireless and telephone applications and on his advice AT\&T bought the rights on the "de forest audio tube" in 1913. By 1915, the improved vacuum tube went into service for the first trans-continental line (New York - San Francisco). Open wire lines required a large amount of space, were unsightly, and caused problems at river crossings, on intercity routes, and in high density areas in towns. Growth in demand led to attempts to find methods of carrying multiple conversations over a single pair of wires, called the carrier system. Work on such systems began in about 1910. The use of carrier techniques, however, exacerbated the repeater amplifier problem since carrier systems need higher bandwidth. In 1921, Black, working at the Western Electric Company (later part of Bell laboratories), produced a report in which he evaluated the requirements for transmitting thousands of channels over a transcontinental link, this would need 1000 amplifiers in series. This was an ambitious and audacious proposal since the engineers at that time were struggling to make channels systems with 10 to 12 repeaters work.

Black requested permission to work on amplifier design which was granted on the condition that it did not interfere with his other work. Black was close to giving up when he one night, at 2am, on his way home from work influence by a lecture of Steinmetz, restated the amplifier problem. The reformulation enabled him to accept that the amplifier could be imperfect and that "its output was composed of what was wanted plus what was not wanted". Very quickly Black formulated a solution. A repeater based on this idea was built, tried in the laboratory in March 1923, and found to work as expected. The amplifier, however, was not perfect and not yet suitable for general applications as it required two identical amplifiers. for several years Black wrestled with this problem. The solution came to him on Saturday morning (2 August 1927) on his way to work. Black sketched the solution and the equations on a copy of new York Times and had the invention witnessed when he came to work. It was the negative feedback amplifier that he had found. Although the invention was submitted to the U.S Patent Office on August 8, 1928, more than nine years would elapse before the patent was issued on December 21, 1937. One reason for the delay was that the concept was so contrary to establish beliefs that the Patent Office initially did not believe it would work.

Except for Black, there were also other persons that made contributions in the area.
- Harry Nyquist, born in 1889 in Nilsby Sweden, moved to the U.S.A in 1907 and worked for Bell Labs in New York between 1919 and 1945. In 1932 he published the paper" Regeneration Theory", the paper was an outcome of Black's request on assistance in understanding the conditions under which the

feedback amplifier is stable. Underlying the whole paper is the understanding at which he had arrived in 1924, that the behavior of a system can be analyzed in terms of its frequency characteristics and that all impressed signals can be described in terms of their Fourier components.

- Hendrik W. Bode. Bode's involvement in feedback circuits began in 1934 when he was asked to design a variable equalizer to compensate for the effect of temperature variations in a coaxial line transmission system that was being developed. Bode argued that the theoretical condition for stability was that the phase shift must not exceed 180 degrees until the loop gain is reduced to 1 or less. He called these margins: the phase margin and the gain margin.

University

Post-script file

Unknown to Routh and Hurwitz, Russian mathematicians and engineers were also working on the problem of dynamic stability. The work had been started by Wischnegradski at Practical Technological Institute in St. Peterburg in the 1870s. The major breakthrough, however, came in 1892 when Alexandr Michailovich Lyaponov (1857-1918), a former student of P.L. Chebyshev at the University of St. Petersburg and now Professor of Mechanics at the University of Kharkov, presented his doctoral dissertation on 'The general problem of the stability motion'. Lyaponov, in addition to being closely connected with the Russian work, was well aware of the work on dynamic stability being done outside Russia. He frequently cites the work of Routh, as well as works by Hermite, and in the introduction acknowledges his debt to Poincaré. In 1917 he had to move from St. Petersburg to Odessa on his doctors order. Lyaponov was in a poor shape and his eyesight was bad. In the same year his wife got tuberculosis and passed away. The year after his family estate burned during the Russian revolution and the old library, built by his father and his grand-father burned to the ground. This same year he confessed suicide. The importance of Lyaponov's work is that the methods he developed are applicable to nonlinear systems. His work, however, remained largely unknown in the English-speaking world until after the Second World War.

James Clarke Maxwell was born in South Glasgow in 1831. He studied at the University of Edinburgh. Later on he became professor of Natural Philosophy in Aberdeen, professor in Physics and Astronomy at Kings Collage in London, professor in Experimental Physics at Cavendish Laboratory. He had a very broad interest. In 1868 he published a control paper on stability concepts. Edward John Routh was born in Quebeck in Canada in 1831. He solved Maxwells problem 3rd order, the solution was included in his book. He was known as a good teacher at Cambridge.

Adolf Hurwitz was born in 1858. Hurwitz obtained stability conditions on higher order polynomials in terms of certain sub-determinants.

Process Industry

Post-script file

Around the turn of the nineteenth century there was an industrial need of instruments for sensing, recording and controlling. The need to measure pressures, flows and above all temperatures was common to a wide range of industries and the ability to measure a quantity is prerequisite to controlling it. In the USA several instrument manufacturing companies were formed and a lot of instrument makers began to produce instruments suitable for industrial use in process and manufacturing industries. In England and in Germany similar instrument companies were developing.

During the 1920's design leadership in industrial instruments passed from Europe to the USA. In the mid 1930 there were more than 600 instrument companies in the USA, from which we today still have Siemens, Taylor Instruments, Honeywell and Foxboro, just to mention a few. The early automatic controllers were, with few exceptions of three types:
- electrical relay with solenoid operated valve which gave on-off action.
- electrical relay with motor operated valve which gave so-called narrow-band proportional action.
- pneumatic relay.

Already in 1922 the value of a PID controller had been shown theoretically by Minorsky. Its use was also suggested by others at that time. From the initial on-off (relay) systems there was a gradual change to proportional continuous control. One was well aware of that "wear and tear" on equipment is expensive because of the constant speeding up and slowing down on equipment. The integral action, or the reset-action, became known in the 1920's and in the beginning of the 30's the derivative action came.

The development of process control concepts, theory and devices, during the late 30's was largely advanced by engineers working for instrument companies. Some examples are given:
- A. Ivanoff worked for the George Kent Company in England. He was one of the first persons that tried to develop a theoretical basis that would support analysis and synthesis of temperature controllers.
- C.E.Mason and G.A. Philbrick were employed by the Foxboro Company. Mason patented in 1930 a controller, later known as the Foxboro Stabilog, that except from wide-band proportional action also had integral action. This controller could eliminate the steady-state offset that occurs with simple proportional action. Later on Mason worked together with Philbrick. In one of their papers, published in 1940, one can find one of the earliest known lock diagram.
- J.G Ziegler and N.B. Nichols were employed by the Taylor Instrument Companies. They explained their methods for tuning controllers and process engineers were introduced to frequency domain techniques developed by the communications engineers.
- Ed S. Smith worked for Builders Iron Foundry. In 1936 he drew attention to the importance of user adjustable parameters. Before this the parameters in the controller had all been fixed.

Power Systems

Post-script file

In the 17th century with the development of electrical technology a number of automatic controls emerged: servomechanisms for controlling arc lamps, voltage and current regulators and methods of motor control. The emphasis was mainly on steady-state behavior. Controllers were developed by empirical methods and there was little analysis.

At first electrical distribution was limited to the supply of surplus power from public supply companies. The benefits of central generation had been recognized earlier by Edison, who used a 240 V direct current-system.

In the late 1880s G. Westinghouse in the USA and S. Z. de Ferranti in England were demonstrating the superiority of the alternating-current system for electrical distribution. In these early systems, where the load was largely lighting circuits, the emphasis was on voltage (or current) regulation, the frequency being allowed to vary. The most widely used vibrating regulator was the 'Tirill' regulator, which had been designed by the General Electric Company in 1902. Many other forms of voltage regulators were developed, by Brown Boveri and Metropolitan Vickers.

With the gradual increase in the proportion of frequency-sensitive components in the load maintenance of frequency became more important. By the 1920s improvements in frequency control were being sought. At the same time the movement towards the interconnection of power system, with the exchange of power across the lines was beginning. This brought into focus the question of system stability.

It was quickly realized that 'the governor alone cannot maintain constant frequency, and it is necessary therefore to provide some means outside of the governor proper to exercise a supervisory control either manually or automatically', a return to the ideas of speed control first proposed by the Siemens brothers. Various frequency regulators were developed commercially, the most accurate being the GEC-Warren master frequency regulator. It used a synchronizing motor to adjust the operating point of the turbine governor. In practice a compensating network was introduced between the synchronizing motor and the governor. From which emerged a wide recognition of the lack of analytic and experimental analysis of the dynamics on turbine governors, in several papers about 1940.

The lack of analysis of the dynamics of power-system operation is surprising, as the lead had been given at the beginning of the century, by the study of the stability of coupled alternators, by John Hopkinson in 1884. Throughout the 1920s and 1930s the 2-machine stability problem continued to be studied, since it provided an illustration of the transient behavior of alternating-current systems and also because many multi-machine problems can be reduced to the 2-machine problem, which could be described by a second order differential equation. In the 1930s solutions to this equation were obtained by using for example the differential analyzer. In the following year, again using the differential analyzer, Concordia investigated the effects of continuous tie-line control on the stability of interconnected systems. Voltage regulators were analyzed by Hanna and Boice in 1939 and 1940, and in 1941 Higgs-Walker in England and Concordia in the USA analyzed power-system governors.

In all these papers stability was assessed by using Routh-Hurwitz algebraic criteria. Higgs-Walker obtained the theory from Tolle, while Boice and Concordia make direct reference to Routh's Advanced rigid dynamics; Concordia even refers to Maxwells paper 'On governors'.

The problems of power-system stability although recognized early did not lead to any theoretical developments in control systems, partly because adequate practical solutions were obtained by the use of manual supervisory control, but mainly because the problems were too complicated. Not only were the controllers nonlinear, but the problem was multi-variable.

Power Systems

Post-script file

During the 17th century in the United States and England there was a recognition that as ships increased in size, power assisted steering would be needed. The solution appeared to lie in the use of steam power to operate the rudder. The first steam steering engine was invented by Frederick E. Sickles in 1849 and later used in the steamship "Augusta". A steering engine incorporating feedback was patented in 1866 by J.McFarlane Gray and, appropriately enough, first saw service in the largest and most advanced ship then afloat, Brunels "Great Eastern".

First in 1873 the word "servo" had been stated in the book "Le Servo-Moteur ou Moteur Asservi" by Jean Joseph Léon Farcot, in which he describes the various designs of steam steering apparatus developed by the company of Farcot and Son. Farcot have equal claim with Gray as the inventor of steering engines incorporating feedback. The work of Joseph Farcot represents an important step in the development of control engineering, for not only were his inventions and designs of practical importance, but his book was the first extensive account of the general principles of position control mechanisms.

The use of steam powered servo motors for positioning heavy objects spread rapidly: B oth the French and British navies was alert to the use of steam for the operation of gun turrets. However, use of steam was not an entirely suitable medium. Because it was difficult to stop the guns precisely in the loading position. However, this was solved by invention of the hydraulic servomechanisms during the last quarter of the 19th century.

The most advanced servomechanism developed during the last quarter of the 19th century were those used in torpedoes. The pneumatic and mechanical servomechanisms for torpedo controls were developed during the late 1860s and the 1870s. Robert Whitehead (1823-1905) showed a torpedo driven by pneumatic engine for Austrian Navy in 1869. The depth control system he had developed was referred to as 'the secret' for 25 years, this was to make proportional feedback from depth and attitude. In 1895 Ludwig Obry of the Austrian Navy invented a gyroscopic device for use in torpedoes.

Also, from the turn of the century, there was a growing interest in stabilization of ships and in automatic steering, both which encouraged interest in servomechanism. In 1908 Elmer Sperry came up with the 'active stabilizer', a gyroscope used on board ships.

With the development of steering engines during the latter quarter of the 19th century it is not surprising that attempts were made to connect the steering engine to the magnetic compass. The major contributions to the development of a practical automatic steering system were made by the Sperry Gyroscope Company. In 1912 Elmer Sperry started his work in developing his auto pilot for the steering of ships, it was called the Metal-Mike. The Metal-Mike behaved as an experienced helmsman.

The first systematic attempt to model and analyze an automatic following device was carried out by Nicolas Minorsky (1885-1970). The analysis was published in 1922 in th paper "Directional Stability of

Automatically Steered Bodies. Minorsky's work had little immediate impact; it was an achievement to show theoretically that good automatic steering required 3-term control, but there was a considerable problem in designing and building reliable apparatus to measure and combine the three terms. In this area Minorsky was in competition with a skilled inventor (Sperry) backed by sound engineers, and also with Anschutz Company, which had a 20-year start and time to build up a good engineering team.

Ships

Post-script file

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Flight

Post-script file

The subject of airplane stability and control appeared as a recognizable entity at the turn of the century, largely owing to the pioneering theoretical work of Lancaster and Bryan. Its experimental beginnings, of course go back much farther. A long list of inventors and scientists made contributions from Sir George Cayley, who experimented with flying models in 1843, to the Wright brothers, who finally made successful flights in 1903. The most difficult problem that these experimenters encountered and the last to be surmounted, was the achievement of satisfactory flying qualities. It was here that the Wright brothers made their most notable contribution.

The pioneers of aviation, Lilenthal, Maxim, Lanchester, Pilcher, Chancute and Langley, attempted to build aircraft which had inherent stability. The Wright brothers rejected the dogma of inherent stability. The pilot was required to 'fly' their aircraft; to enable him to do so he was provided with powerful control surfaces. However, to successfully operate these controls, the pilot needed to be able to sense the motion of the aircraft; in good conditions and with visual contact with the ground this he could do, but in fog or at night, he lacked the necessary visual information. The early practitioners saw two possibilities: provide the pilot with instruments to indicate the behavior of the aircraft or provide automatic control.

The outstanding early contributions came between 1912 and 1914 from Elmer Sperry (1860-1930) and his son Lawrence who demonstrated the Sperry autostabiliser in Paris 1914. In a superb publicity stunt Lawrence stood with his hands off the controls while his mechanic walked along the wing of the aircraft: the aircraft maintained straight and level flight.

Before autostabilisers became commercially available, the First World War began. War changed the requirements: flights were now of short duration, fighters had to be highly maneuverable and pilots were intensely proud of their flying skill; the pilot was firmly within the control loop. The emphasis was on the provision of a range of instruments to help the pilot, such as turn indicators, artificial horizons and slip indicators, and not on autostabilisers. There was one area, however, where stabilizers were still required, and that was for bombing.

After 1918 considerable interest in radio-controlled aircraft developed, with a consequent interest in autopilots. This work was largely carried out by the military authorities, in Britain at the Royal Aircraft Establishment (RAE), in the USA by the Naval Research Laboratory.

The 1930s saw the development of commercial autopilots, i.e. the Sperry autopilot, the Siemens autopilot. Elmer Sperry was a leading contributor with his aircraft auto pilots and auto stabilizers to the achievement of satisfactory flying qualities. He modified the gain according to the speed. In September 1947 a C-54 passed the Atlantic with no human touching the controls from start until landing. The plane was controlled with Sperrey's A-12 auto pilot.

Military autopilots were also developed by the RAE, and the Siemens, Askania, Sperry Gyroscope, General Electric and Honeywell Companies. The basis of all the autopilots developed was some form of stabilized platform and a gyrocompass, but there was a considerable differences in the methods used to 'pick off' the signals and operate the various actuators. The early British systems were pneumatic whereas the American and German designers used hydraulic or mechanical systems. Gradually electrical components were introduced, but wholly electrical units were not produced until after the Second World War.

The engineers concerned with the flight control were one of the first disciplines who first recognized the value of the stability criteria developed by Routh. From the beginning of the 20th century until the 1940s, occasional use was made of the Routh-Hurwitz inequalities in testing for stability, but use did not become widespread until after the Second World War.

The importance of the development of autostabilisers and autopilots to control engineering is in the development of components and in the idea of a control circuit combining several signals. The systems were not designed on the basis of any control theory and their general complexity, involving a mixture of electrical, mechanical and pneumatic (or hydraulic) components, as well as nonlinearities, was not conducive to the development of any theory. Also, computational difficulties seem to have prevented development of an interest in the analysis of aircraft control systems.

Project in the course History of Control: Some Awards in Automatic Control

Lennart Andersson
Johan Nilsson
Anders Robertsson

Department of Automatic Control
Lund Institute of Technology

History of Control

Historical sites: Tree | IFAC award | CDC award | ACC award | Other award | WWW sites

IFAC - Giorgio Quazza Medal

The Giorgio Quazza Medal This is an IFAC award to a distinguished control engineer, presented at each IFAC Triennial International World Congress as a memorial to the late Giorgio Quazza, a leading Italian electrical and control engineer who served IFAC in many capacities in a most distinguished manner. The medal is awarded by the IFAC Council on the recommendation of a selection committee. A prize of sfr 2000.-- is presented to the recipient together with the medal.

- 1981 John F. Coales
- 1984 Yakov Z. Tsypkin
- 1987 Karl J. Åström
- 1990 Petar Kokotovic
- 1993 Edward J. Davison
- 1996 Alberto Isidori

CDC - Bode Price

- 1989 Gunter Stein
- 1990 David G. Luenberger
- 1991 Petar V. Kokotovic
- 1992 Brian D.O. Anderson
- 1993 Michael Athans
- 1994 Gene F. Franklin
- 1995 Kumpati S. Narendra

ACC - Richard E. Bellman Control Heritage Award

The award is given for distinguished career contributions to the theory or applications of automatic control. The Bellman Control Heritage Award is the highest recognition of professional achievement for U.S. control systems engineers and scientists. Richard E. Bellman, for whom the award is named, was an applied mathematician who pioneered the development of system theory as an academic discipline in the 1950s and 1960s. His accomplishments are described in IEEE Transactions on Automatic Control, 1984. The Bellman Award is unique among the AACC awards in that it is made for lifetime contributions to control and systems engineering. Such contributions may cover a range of technical areas or may have been put into practice in several different fields. The winner of

the Bellman Award usually has been involved with the interaction of control or system theory with other scientific disciplines, with the engineering profession, and/or with the implications of controls for society at large.

- **1979 Hendrik W. Bode**
- **1980 Nathaniel B. Nichols**
- **1981 Charles S. Draper**
- **1982 Irving Lefkowitz**
- **1983 Richard E. Bellman**
- **1984 John V. Breakwell**
- **1985 Harold Chestnut**
- **1986 John Zaborszky**
- **1987 John Lozier**
- **1988 Walter R. Evans**
- **1989 Roger W. Brockett**
- **1990 Arthur E. Bryson, Jr.**
- **1991 John G. Truxal**
- **1992 Rutherford Aris**
- **1993 Eliahu I. Jury**
- **1994 Jose B. Cruz, Jr.**
- **1995 Michael Athans**
- **1996 Elmer G. Gilbert**

Other Awards

- **ASME - Rufus Oldenburger Medal**

Historical Internet Links

- **Vannevar Bush**

Lennart Andersson <lennart@control.lth.se>
Johan Nilsson <johan@control.lth.se>
Anders Robertsson <andersro@control.lth.se>

Karl Johan Åström

Karl Johan Astrom was educated at the Royal Institute of Technology (KTH), Stockholm where he has held various teaching appointments. He received Docteur Honoris Causa from l' Institut National Polytechnique de Grenoble in 1987. He has been Professor of Automatic Control at Lund Institute of Technology since 1965. Before that he worked for IBM and the Research Institute of National Defence in Stockholm. His interest cover broad aspects of automatic control, stochastic control, system identification, adaptive control, computer control and computer-aided control engineering. He has published five books: Reglerteori (in Swedish); Introduction to Stochastic Control Theory; Computer Controlled Systems - Theory and Design (coauthor, B. Wittenmark); Automatic Tuning of PID Controllers (coauthor, T. Hagglund); and Adaptive Control (coauthor, B. Wittenmark). He has contributed to several other books and he has written many papers. The paper "System Identification", Automatica, 7, 1971, 123-162 (coauthored with P. Eykhoff) is a Citation Classics. He has received an Automatica Prize Paper Award, and the Donald G. Fink Prize Paper award from IEEE. He holds some patents. He is a Fellow of the IEEE, a member of the Royal Swedish Academy of Sciences, the Swedish Academy of Engineering Sciences (IVA), and the Royal Physiographical Society. He has received several awards among them the Rufus Oldenburger Medal, the Quazza Medal, the IEEE Control Systems Science and Engineering Award and the IEEE Medal of Honor.

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Petar V. Kokotovic

Petar V. Kokotovic received graduate degrees in 1962 from the University of Belgrade, Yugoslavia, and in 1965 at the Institute of Automation and Remote Control, USSR Academy of Sciences, Moscow. From 1959 to 1966 he was with the Pupin Research Institute in Belgrade, Yugoslavia, and then, until March 1991, with the Department of Electrical and Computer Engineering and the Coordinated Science Laboratory, University of Illinois, Urbana, where he held the endowed Grainger Chair. He supervised twenty-five Ph.D. students. With them he coauthored several books and numerous papers on sensitivity analysis, singular perturbations, large scale systems, and adaptive control. He has held visiting appointments with research institutions in the United States, France, Italy, Switzerland, and Australia. His industrial consulting activities include Ford Motor Company and General Electric Company. Dr. Kokotovic has served on the Board of Governors and IDC of the Control Systems Society, on committees of the International Federation of Automatic Control (IFAC), and as an Associate Editor of several technical journals.

Recognitions and Honors:

* Fellow, IEEE (1980)
* Outstanding Paper Award (IEEE Transactions on Automatic Control, 1983)
* Eminent Faculty Award (1987)
* Quazza Medal of the International Federation of Automatic Control (1990)
* IEEE Bode Prize Lecture (1991)
* Outstanding Paper Award (IEEE Transactions on Automatic Control, 1993)

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Edward J. Davison

Davison awarded Quazza Medal

E.J. Davison has been awarded the 1993 Quazza Medal by the International Federation of Automatic Control (IFAC) for his "seminal contributions to linear systems theory and his work on industrial applications". The medal is the highest award granted by IFAC and is presented once every three years. The award was presented at the 12th IFAC World Congress held in Sydney, Australia, July 18-23, 1993.

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David G. Luenberger

Prof. Luenberger is well known for his work in systems analysis and mathematical optimization. His doctoral dissertation led to the concept of the "Luenberger Observer," which is widely referenced in control theory. He is the author of over 60 technical papers and three major textbooks on optimization, mathematical programming, and dynamic systems. In 1971, he served as Technical Assistant to the Director at the Office of Science and Technology, Executive Office of the President, Washington D.C. In 1976, he was a visiting professor at MIT; and in 1986 he was a guest professor at the Technical University of Denmark. As a consultant to several companies, he has helped formulate and solve problems in a wide range of application areas. His current research is in mathematical systems analysis and systems economics. He is a Fellow of the IEEE and was President of the Society for Economic Dynamics and Control, 1987-88, and a member of several professional organizations.

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Brian D.O. Anderson

Brian D.O. Anderson was born in Sydney, Australia, and received his undergraduate education at the University of Sydney, with majors in mathematics and electrical engineering. He subsequently obtained a Ph.D. degree in electrical engineering from Stanford University. Following completion of his education, he worked in industry in Silicon Valley and served as a faculty member in the department of electrical engineering at Stanford. In 1967, he joined the electrical engineering department at the University of Newcastle, Australia, where he remained until the end of 1981. At that time he became professor of Systems Engineering at the Australian National University. His research interests are in control engineering and signal processing, and he has co-authored a number of books in these fields, as well as research papers. He is a Fellow of the Royal Society, the Australian Academy of Science, Australian Academy of Technological Sciences and Engineering, and the Institute of Electrical and Electronic Engineers, and an Honorary Fellow of the Institute of Engineers, Australia. He holds a doctorate (honoris causa) from the Catholic University of Louvain, Belgium. He has served or is serving on government committees and councils including the Prime Minister's Science and Engineering Council, and is also a company board member. He is serving a term as President of the International Federation of Automatic Control from 1990 to 1993.

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Michael Athans

Michael Athans was born in Drama, Macedonia, Greece on May 3, 1937. He came to the United States in 1954 for a one year exchange visit under the auspices of the American Field Service and he attended Tamalpais High School in Mill Valley, California. Next he attended the University of California at Berkeley from 1955 to 1961 where he received his BSEE in 1958 (with highest honors), MSEE in 1959, and Ph.D. in control in 1961.

From 1961 to 1964 he was employed as a member of the technical staff at the MIT Lincoln Laboratory, Lexington, Mass. where he conducted research in optimal control and estimation theory. Since 1964 he has been a faculty member in the MIT Electrical Engineering and Computer Science department, where he currently holds the rank of Professor. He also was the director of the MIT Laboratory for Information and Decision Systems (formerly the Electronic Systems Laboratory) from 1974 to 1981. In 1978 he co-founded ALPHATECH Inc., Burlington Mass., where he serves as Chairman of the Board of Directors and Chief Scientific Consultant. He has also consulted for numerous other industrial organizations and government panels. He has acted as the thesis supervisor for 42 MIT doctoral students to date. In 1995 he was Visiting Professor in the Department of Electrical and Computer Engineering at the National Technical University of Athens, Greece.

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Gene F. Franklin

Gene F. Franklin has been at Stanford University, Stanford, CA, since 1957, where he is currently Professor of Electrical Engineering. He received his degrees at Georgia Tech, GA; M.I.T., MA and Columbia University, NY, completing the doctorate in 1955. His research and teaching interests are in the area of digital control, with current emphasis on model order reduction, adaptive control, including algorithms for implementation on microprocessors, and development of computer-aided design tools for control. He is co-author of three books on control, including Digital Control of Dynamic Systems, Second Edition, Addison-Wesley, 1990, with J.D. Powell and M.L. Workman and Feedback Control of Dynamic Systems, Third Edition, Addison-Wesley, 1994, with J.D. Powell and A. Emami- Naeini. He is a Fellow of IEEE and was Vice-president for Technical Affairs of the IEEE Control Society in 1986 and 1987. In 1985 he received the Education Award of the American Automatic Control Council, and in 1990 he and his co-authors received the IFAC Award for the best textbook for Feedback Control of Dynamic Systems. He has been selected to give the Bode Lecture before the IEEE Control Society at the Conference on Decision and Control, December 1994.

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Kumpati S. Narendra

Kumpati S. Narendra received the M.S. and Ph.D. degrees from Harvard University, Cambridge, Massachusetts in 1955 and 1959, respectively. He joined the Department of Engineering and Applied Science, Yale University, New Haven, Connecticut in 1965 as Associate Professor and became Professor of Engineering and Applied Sciences in 1968. He was Chairman of the Department of Electrical Engineering from 1984 to 1987. Currently, he is Director of the Center for Systems Science and the Neuroengineering and Neuroscience Center at Yale.

Dr. Narendra is the author of over one hundred and fifty technical publications in the area of systems theory. He is the author of three books, Frequency Domain Criteria for Absolute Stability (co-author J. H. Taylor) published by Academic Press in 1973, Stable Adaptive Systems (co-author A. M. Annaswamy) published by Prentice Hall in 1988, and Learning Automata - An Introduction (co-author M. A. L. Thathachar) published by Prentice Hall in 1989. He is also the editor of four books, Special Issue on Learning Automata (Journal of Cybernetics and Information Science, 1977), Applications of Adaptive Control (co-author R. V. Monopoli) published by Academic Press in 1980, Adaptive and Learning Systems (Plenum Press, 1986), and Advances in Adaptive Control (co-authors R. Ortega and P. Dorato, 1991). His research interests are in the areas of stability theory, adaptive control, learning automata and control of complex systems using neural networks.

Dr. Narendra has served on various national and international technical committees. He was an NSF fellow in India in 1968 and 1977 and a SERC Senior Research Fellow in England in 1973, 1984 and 1987. He has been an Associate Editor of the IEEE Transactions of Automatic Control and the Editor of the Journal of Cybernetics and Information Science and the IEEE Transactions on Neural Networks. At present he is an-Associate Editor of the journals Adaptive Control and Signal Processing. Kybernetes, Neural Computing and Neural Networks. He has also been consultant for the control groups at Honeywell, Inc.; the Sperry Rand Research Center; Dynamics Research Corporation; Bell Aero-Systems; Schlumberger; Sikorsky Aircraft; AT&T Long Lines Division, Borg Warner Corporation; General Motors Corporation; Neural Applications Corporation; Amoco Research Center; and JPL.

Dr. Narendra is a member of Sigma Xi, and a Fellow of the American Association for the Advancement of Science, IEEE and IEE (UK). In 1995, he was made a member of the Connecticut Academy of Science and Engineering. He was the recipient of the 1972 Franklin V. Taylor Award of the IEEE Systems, Man and Cybernetics Society, the George S. Axelby Best Paper Award of the IEEE Control Systems Society in 1988, the Education Award of the American Automatic Control Council in 1990, the Outstanding Paper Award of the Neural Network Council in 1991, the Neural Network Leadership Award of the International Neural Network Society in 1994, and the Bode Prize of the Control Systems for 1995. He was made a Distinguished Visiting Scientist at the Jet Propulsion Laboratory for 1994-95. He received an honorary doctorate (D.Sc) from Anna University in Madras. India in 1995.

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Photo and Text: Proceedings CDC 95

Charles S. Draper

The "father of inertial navigation," Charles Stark Draper evolved the theory, invented and developed the technology, and let the effort that brought inertial navigation, which allows vehicles to sense changes in direction by linking gyroscopes and accelerometers along three axes, to operational use in aircraft, space vehicles, and submarines. A pioneer among aircraft engineers, Draper's monumental efforts on the Apollo program and on the guidance systems for strategic missiles bear witness to his genius. Modern aircraft the world over travel their global routes with pinpoint accuracy with inertial guidance systems derived from this original inventions.

Born Windsor, Missouri, on October 2, 1901, "Doc" Draper began his college work in arts and sciences at the University of Missouri in 1917. In 1919 he entered Stanford University, California, and graduated in 1922 with a B.A. in psychology. He entered MIT the same year, earning a B.S. in Electrochemical engineering in 1926 and an Sc.D. in Physics in 1938.

As a member of the MIT faculty and head of the Department of Aeronautics and Astronautics, Draper developed an extensive program in instrumentation and control. His team of students and technicians at MIT expanded to become the MIT Instrumentation Laboratory, and in 1973 that lab became a separate, nonprofit research and development laboratory--The Charles Stark Draper Laboratory, Inc.

By the time of his death in 1987, Dr. Draper had received more that 70 honors and awards in the United States, France, the United Kingdom, Germany, Switzerland, Czechoslovakia, and USSR. He was member of the U.S. National Academy of Engineering, the U.S. National Academy of Sciences, and the French National Academy. His many awards included the National Medal of Science from President Lyndon Johnson, the prestigious Langley Medal of Smithsonian Institution, the Robert H. Goddard Trophy, and the National Academy of Engineering' Founders Award.

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Harold Chestnut

Control Heritage Award for control for distinguished career contributions to the theory or application of automatic control.

Harold Chestnut's career started before World War II as an MIT Cooperative Student to the General Electric Company and continued as a GE employee throughout his entire working life until retirement in 1983. Presently he serves as President of the SWIIS Foundation which is devoted to improving international stability. His early work was on the use of control systems for electric power systems and for military fire control. This experience led to the writing with Robert W. Mayer of two books on "Servomechanisms and Regulating Systems Design". Later in the 1960's he wrote the books "Systems Engineering Tools" and "Systems Engineering Methods". These books were devoted primarily to the use of control for space, industrial, and management purposes. Chestnut has served as president of such organizations as the American Automatic Control Council, The International Federation of Automatic Control, and the Institute of Electrical and Electronic Engineers, the first two of which he helped found. He was made a Fellow of the IEEE in 1962 and a member of the National Academy of Engineering in 1974. In 1981 he was the recipient of the Honda Prize for Ecotechnology. In recent years he has been active in trying to understand better the impact of technology on society and how man-machine systems can make this impact more beneficial for society. Chestnut received a BSEE '39 and a MSEE '40 from the Massachusetts Institute of Technology and Honorary Doctorates in Engineering from Case Western Reserve University in 1966 and Villanova in 1972.

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Photo and Text: Proceedings ACC 85

John Zaborszky

The Richard E. Bellman Control Heritage Award

John Zaborszky was born in Budapest, Hungary, on May13,1914. He received the Diploma of Engineering in 1937 and the D.Sc. degree in 1943 from the Royal Hungarian Technical University, Budapest, Hungary. Prior to 1949 he was Chief Engineer with the Budapest Municipal Power System. He was also a professor at the University of Missouri, Rolla, and since 1956 he has been with Washington University, St. Louis, Missouri, where he developed the new Department of Systems Science and Mathematics which emphasizes control and systems engineering and of which he is currently Chairman. He has been a consultant to McDonnell Douglas, Emerson Electric, Westinghouse, Hi-Voltage Equipment and NIH. He has published two books and many technical papers. Within the IEEE, he was instrumental in the merger of the PGAC of IRE and the Feedback Systems Committee of AIEE, and in the formation of the Control Systems Society as one of the first three IEEE societies. Dr. Zaborszky was President of the IEEE Control Systems Society in 1970 and a member of the IEEE Board of Directors and Director of Division I during 1974-1975. He was President of the American Automatic Control Council (AACC) during 1980- 1981. He is a member of the National Academy of Engineering, a Fellow of IEEE, a distinguished member of the IEEE Control System Society and a recipient of the IEEE Centennial Award.

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Photo and Text: Proceedings ACC 86

Walter R. Evans

The Richard E. Bellman Control Heritage Award

Awarded to Walter R. Evans for his very significant contribution to the field of automatic control systems analysis and synthesis by inventing the root locus technique.

Walter R. Evans was born January 15, 1920 in St. Louis, Missouri. He received his B.S. in Electrical Engineering from Washington University in St. Louis in 1941 and his M.S. in E.E. from the University of California, Los Angeles in 1951. From 1941 to 1946 he was with the Advanced Engineering Training Program of the General Electric Company in Schenectady, New York where he was teaching for two years after he completed the three year program. From 1946 to 1948 he was on the Electrical Engineering staff at Washington University in St. Louis.

In 1948 Evans made a very significant contribution to the field of automatic control analysis and synthesis by inventing the root locus technique. For feedback control systems the root locus method provides a direct display of system stability and natural characteristics. It also shows graphically precisely how these qualities are influenced by changes in design parameters. Evan's Root Locus method has been and will remain one of the fundamental methods in the analysis and design of control systems.

From 1948 to 1959 he was employed at Autonetics, a Division of North American Aviation, now called Rockwell International. He was with the Inertial Autonavigator Department in charge of the laboratory and first flight tests of the first purely inertial navigator in 1950. As Systems Group Leader of the Electro-Mechanical Engineering Department, he was responsible for the stable platform and housings for all navigator systems. From 1957 to 1959 he was Assistant Section Chief of the Component Engineering Inertial Navigator Engineering Department.

From 1959 to 1971 he was on the technical staff of the Guidance and Control Department of the Re-Entry Systems Operation of Ford Aeronutronic at Newport Beach, California. From 1971 to 1980 he served as a "trouble shooter" at Rockwell International on the technical staff of the manager of the Strategic System Division of Autonetics, and his advice was utilized in a wide range of programs related to servo systems at many of the Southern California Divisions of the company.

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Photo and Text: Proceedings ACC 88

Roger W. Brockett

The Richard E. Bellman Control Heritage Award

Awarded to Professor Roger W. Brockett for his significant contributions to the field of control theory.

Professor Brockett is on the faculty of the Division of Applied Sciences at Harvard University, holding the title of Gordon McKay Professor of Applied Mathematics. He has published extensively in the field of automatic control and related areas of electrical engineering and applied mathematics. Experimental and theoretical aspects of robotics, including aspects of manipulation, computer control, and sensor data fusion, are the focus of his present work. In addition to being Associate Director of the Brown-Harvard-MIT Center for Intelligent Control Systems, he also collaborates with colleagues at the University of Maryland through the Maryland-Harvard NSF Engineering Research Center on Systems Engineering. Over the past twenty-five years Dr. Brockett has been involved in the professional activities of the IEEE, SIAM, and AMS, having served on the advisory committees and editorial boards for several groups in these societies. He has presented lecture series in connection with NATO, CBMS, and NASA meetings, as well as having held visiting positions at more than a dozen universities. In addition to having been a founding co-editor of the journal Systems and Control letters, he is the author of an influential textbook, Finite Dimensional Linear Systems, and has been he thesis supervisor of more than 40 Ph.D. students at Harvard and MIT. He is a Fellow of the IEEE and has held a Guggenheim fellowship for the study of mathematical system theory.

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Text: Proceedings ACC 89

Arthur E. Bryson, Jr.

The Richard E. Bellman Control Heritage Award

Awarded to Arthur E. Bryson, Jr. for his significant contributions in the field of Optimization and Control Theory.

Arthur Bryson was a U.S. Naval Officer during World War II. He received the B.S. degree in Aeronautical Engineering from Iowa State College in 1946 and the Ph.D. degree in Aeronautics from the California Institute of Technology in 1951. Prior to receiving his doctorate, he was a wind tunnel engineer at United Aircraft Corp. From 1950 to 1953, he was an Aerodynamics Engineer with Hughes Research and Development Labs. He joined Harvard University in 1953 as an Assistant Professor of Mechanical Engineering, rising to Professor and remaining with the Harvard faculty until 1968. He then joined the faculty of Stanford University, becoming Chairman of the Department of Applied Mechanics (1969-1971), Chairman of the Department of Aeronautics and Astronautics (1971-1979), and the Paul Pigott Professor of Engineering (1972-present).

Professor Bryson's research began in aerodynamics and transitioned to the control and dynamics of physical systems, most notably aircraft and spacecraft. He is co-author (with Y.C. Ho) of the book, Applied Optimal Control, as well as over 100 technical papers and reports. From 1976 to 1978, he was Chairman of the Aeronautics and Space Engineering Board of the National Research Council. He has won a number of awards, including the AACC Education Award (1982), the Pendray Award (1968) and the Mechanics and Control of Flight Award (1980) of the American Institute of Aeronautics and Astronautics, the Westinghouse Award of the American Society for Engineering Education (1969), the Rufus Oldenburger Award of the American Society of Mechanical Engineers (1980), and the Control Systems Science Award of the Institute of Electrical and Electronics Engineers (1984). Professor Bryson is a Fellow of the AIAA and of the American Academy of Arts and Sciences, and a Member of the National Academy of Engineering, National Academy of Sciences, ASEE, Sigma Xi, and Tau Beta Pi.

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Text: Proceedings ACC 90

John Truxal

The Richard E. Bellman Control Heritage Award

Awarded to John G. Truxal, in recognition of life-long contributions to the field of automatic control as an author, teacher, and academic administrator, and for his continuing efforts to foster understanding of the role of technology in the conduct of human affairs.

John Truxal was a U.S. Naval Officer during World War II. He received the A.B. degree from Dartmouth College in 1944, as well as S.B. and Sc.D. degrees in Electrical Engineering from the Massachusetts Institute of Technology in 1947 and 1950. He began his academic career at Purdue University, where he was an Assistant and Associate Professor of Electrical Engineering (1950-1954). He transferred to the Polytechnic Institute of Brooklyn in 1954, becoming Professor and Chairman of Electrical Engineering (1957-1961) and Vice President (1961-1972). He then joined the State University of New York at Stony Brook as Dean of Engineering and Applied Sciences (1972-1976), as Professor (1976-1977), and as Distinguished Teaching Professor (1977-Present). He was Director of the National Coordinating Center for Curriculum Development (1976-1985) and is Director of the Stony Brook Center of the New Liberal Arts Program (1985-Present).

Professor Truxal wrote the book, Automatic Feedback Control System Synthesis, which has been called "a bible for a generation of graduate students and practicing engineers," and he has authored or co-authored a number of other books on control engineering, system engineering, and the interactions of people with technology. He has won many awards, including the ISA Education Award, the ORSA Lanchester Award, the IEEE Education Award, and the ASEE Westinghouse Award, and he was granted an Honorary Doctorate of Engineering by Purdue. Dr. Truxal was President of the Instrument Society of America and is a Fellow of the IEEE, ISA, and AAAS. He is a Member of the National Academy of Engineering, as well as ASEE, Phi Beta Kappa, Tau Delta Pi, Eta Kappa Nu, and Sigma Xi.

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Text and Photo: Proceedings ACC 91

Rutherford Aris

The Richard E. Bellman Control Heritage Award

Awarded to Rutherford Aris, in recognition of his life-long contributions to the control and optimization of chemical engineering systems.

Rutherford Aris was born and bred in Dorset on the south coast of England, worked for seven years for I.C.I. on Teeside and taught for two years at Edinburgh University before coming to the Department of Chemical Engineering at the University of Minnesota in 1958. During this period he also spent the year of 1955-56 at Minnesota working with N. R. Amundson on the control of the stirred tank reactor, obtaining some early results on Hopf bifurcation and homoclinic orbits. Not having a Ph.D. when he became an Assistant Professor in 1958 (but fortunately being registered with London University for taking one), he had to write a dissertation which he did in 1959, defending it in 1960. At Amundson's suggestion it was on the application of dynamic programming to the optimal design of chemical reactors, and this brought him into contact with Dick Bellman, in whose Academic Press series "Mathematics in Science and Engineering" a revised version of the dissertation was published as Vol. 3. An introductory monograph Discrete Dynamic Programming was published in 1964. This association with Bellman -- just one of the many lively and stimulating lines of research that permeate the vast "Bellman Heritage" -- continued for twenty years and culminated in a summer spent with him at USC developing mathematical models of aspects of the immune system. Though these were never published, they served as a take-off point for other work of a different character.

The main body of Aris' work is in the analysis of chemical reactors, their dynamics and the stability and control problems that arise. Among the dozen or more books he has published is a two-volume monograph on The Mathematical Theory of Diffusion and Reaction in Permeable Catalysts, published by Clarendon Press in 1975. His whole career has been spent in the Department of Chemical Engineering and Materials Science at the University of Minnesota, and he probably would not have amounted to much without the leadership of Neal Amundson, the stimulus of the excellence of his colleagues, and the good fortune of having worked with a number of students of superb ability that that department has afforded him over the years. He has been a Guggenheim Fellow (Cambridge) and Fairchild Scholar (Caltech) and was made a Regents' Professor at the University of Minnesota in 1978. He is a Fellow of the American Academy of Arts and Sciences and of the Institute of Mathematics and its Applications and a Member of the National Academy of Engineering, the AIChE, SIAM, and the Society for Natural Philosophy. Among his awards is the Damkohler Medal for chemical reaction engineering given by the Deutsche Vereinigung fur Chemie and Verfahrenstechnik. His interests include the philosophy of mathematical modelling, codicology, and Latin palaeography.

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Text and Photo: Proceedings ACC 92

Eliahu I. Jury

The Richard E. Bellman Control Heritage Award

Awarded to Eliahu I. Jury in recognition of his pioneering and extensive contributions to the theory of digital control and digital signal processing over space and time; and in particular, of his development of the modified Z-transformation, the Jury stability test, and the theory and application of matrix inners.

Eliahu I. Jury was born in Baghdad, Iraq, in 1923. He received his degree in Electrical Engineering in 1947 from the Israel Institute of Technology in Haifa, where he was Goldberg Scholar. He received his M.S. degree with distinction from Harvard in 1949 and in 1953 his Sc.D. from Columbia University, where he was Higgins Fellow. In 1954, he joined the Department of Electrical Engineering and Computer Science of the University of California at Berkeley and was promoted to full professor in 1964. he joined the University of Miami in 1981 as Research Professor of Electrical and Computer Engineering.

Professor Jury has authored over two hundred research papers and three books: Sample-Data Control, The Z-transform, and Inners and Stability. His books have been translated into Russian, French, Polish and Japanese. He is the recipient of many national and international honors and awards, including the 1986 Oldenburger Medal from the American Society of Mechanical Engineers, as well as the 1986 Educational Award from the Institute of Electrical and Electronic Engineers, of which he is a Fellow. In 1982 he was awarded an Honorary Doctor of Science by the faculty of the Swiss Federal Institute of Technology in Zurich.

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Text and Photo: Proceedings ACC 93

Jose B. Cruz, Jr.

The Richard E. Bellman Control Heritage Award

Awarded to Jose B. Cruz, Jr. for a distinguished career in automatic control, with pioneering research contributions to sensitivity analysis, feedback theory and game-theoretic control and for extraordinary service to the control field both nationally and internationally.

Jose B. Cruz, Jr., is Dean of Engineering at The Ohio State University. He received his B.S. degree from the University of the Philippines, the S.M. degree from the Massachusetts Institute of Technology, and the Ph.D. degree from the University of Illinois at Urbana-Champaign, all in electrical engineering. Before joining Ohio State in 1992, he was with the University of California, Irvine, for six years where he was Chair of Electrical Engineering for four years. His longest association (three decades) had been with the University of Illinois at Urbana-Champaign, Department of Electrical and Computer Engineering, and the Decision and Control Laboratory of the Coordinated Science Laboratory.

Dr . Cruz is the author or co-author of approximately 200 research papers and author , co-author or editor of six books, Introductory Signals and Circuits (with M.E. Van Valkenburg), Engineering of Dynamic Systems (with W.R. Perkins), Signals in Linear Circuits (with M.E. Van Valkenburg, (translated into Spanish), Feedback Systems (translated into Chinese and Polish), System Sensitivity Analysis, and Advances in Large Scale Systems.

He received the Curtis W. McGraw Research Award of the American Society for Engineering Education, the Halliburton Engineering Education Leadership Award, the IEEE Centennial Medal, the IEEE Richard M. Emberson Award, and the ASEE Centennial Medal. He is a Fellow of IEEE a Fellow of the American Association for the Advancement of Science, and a member of the National Academy of Engineering.

Dr. Cruz served as Editor of the IEEE Transactions on Automatic Control, President of the IEEE Control Systems Society, and Vice President of IEEE for Technical Activities and for Publication Activities. He is the Chairman of the International Program Committee for the 1996 World Congress of IFAC.

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Text: Proceedings ACC 94

Elmer G. Gilbert

Awarded to **Elmer G. Gilbert** for a distinguished career in automatic control, with pioneering research contributions to a broad range of subjects including linear multivariable systems theory, computation of optimal controls, nonlinear systems theory, and motion planning in the presence of obstacles.

Elmer G. Gilbert is Emeritus Professor of Aerospace Engineering and Electrical Engineering and Computer Science at the University of Michigan. He obtained the B.S. and M.S. degrees in Electrical Engineering and the Ph.D. in Instrumentation Engineering, all from the University of Michigan. In 1957 he joined the Department of Aerospace Engineering and later was given a joint appointment in the Department of Electrical Engineering and Computer Science. He has held visiting positions at the United States Air Force Seiler Research Laboratory (1965), the Johns Hopkins University (1974-76 and 1991-92) and the University of Minnesota (1985-86).

During the 1950's and 1960's Dr. Gilbert was active in the development and application of analog and hybrid computers. He was granted eight patents on various computer devices and was a co-founder of Applied Dynamics Incorporated (now Applied Dynamics International).

Dr. Gilbert's interests in control have been distinctive and diverse. He is perhaps best known for the 1963 paper on linear multivariable system theory and the 1969 paper on decoupling by state feedback. Both helped to point the way to large bodies of subsequent research. Other areas in which he has made innovative contributions include: computation of optimal controls, periodic optimal control, feedback control of systems with pointwise-in-time constraints, nonlinear systems theory, motion planning in the presence of obstacles.

Dr. Gilbert is a fellow of the IEEE, a fellow of the American Association for the Advancement of Science, a member of the National Academy of Engineering and a member of the Johns Hopkins Society of Scholars. His awards include: the O. H. Schuck Award for the best paper at the 1978 Joint Automatic Control Conference, Research Excellence and Distinguished Faculty Achievement Awards from the University of Michigan and the 1994 IEEE Control Systems Award.

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