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VISIT TO CONTROL LABORATORIES IN FRANCE

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K.J. Åström

Abstract

This report summarizes some impressions obtained during a two weeks visit to control laboratories in France. The report is written mostly for my own reference. No attempt has been made to make a uniform presentation.

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General

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Special Features

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References

12. ACKNOWLEDGEMENTS

M. MERCUROFF C.N.R.S.

Organization of Research

Mr Mercuroff gave an overview of the French research organization. A brief organization chart is shown in Figure 1.

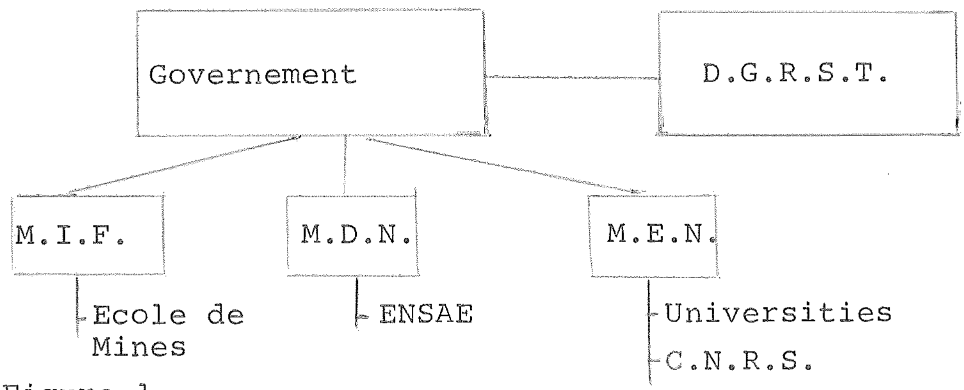

Figure 1.

The governement has an advisory body Délégation Générale à la Recherche Scientifique et Technique (D.G.R.S.T.) which covers all areas of research and forms research policy. D.G.R.S.T. has some funds for research (Action Concertés) but it does not do research itself. All the ministeries are responsible for doing research within their own areas of interest.

Research under M.E.N.

Within the Ministere Education Nationale (M.E.N.) research is carried out by two bodies, the Universities and Centre National de la Recherche Scientifique (C.N.R.S.). The universities split their tasks equally between teaching and research but the C.N.R.S. is fully devoted to research. The C.N.S.R. also supports research in the universities.

Main tasks of the C.N.R.S.

The C.N.R.S. carries out research in essentially two ways through their own laboratories (Laboratoires Propres) and through university laboratories (Laboratoires associés). The Laboratoires Propres are staffed, equipped and run by C.N.R.S.. The Laboratoires Associés are supported by research grants. These may include equipment, temporary and permanent positions. At the moment C.N.R.S. supports about 20.000 people (6000 researchers and 14.000 technicians and administrators). The total budget is of the order of 1500 M Fr. An example of how the research is organized and run in a Laboratoire Propre is found in reference 1. The appropiation of research grants to outside laboratories is done through research proposals submitted by the outside laboratories. The research proposals are evaluated by the Comité National which has 36 sections covering a wide range of subjects, from pure mathematics to epistemology. Each section consists of about 26 members representing university professors, researchers from the C.N.R.S. laboratories, technicians, researchers and external representatives.

Action Thématiques Programmées.

A smalll amount of the C.N.R.S. budget is used in a new way which differs from what was described above. About 50 M Fr. is devoted to Actions Thematiques Programmées. This means that a research program is formulated by C.N.R.S. for an important area. Different groups are then requested to submit research proposals in accordance with the program. This vechicle is used to initiate and stimulate work in important areas which are not appropriately covered. This mode of operation is similar to the Actions Concertées that are done through D.G.R.S.T. There is one difficulty for laboratories to have contracts through Actions Thématiques Programmées. These contracts do not provide for permanent positions which means that the laboratories may run into personel problems. As a rule of thumb it was mentioned that a laboratory devoted to basic research (Science d'analyse) could have about 70 % of its funding from normal funds and about 30 % from contracts, while a laboratory devoted to applied science (Science pour l'Ingénieur) could have as much as 50 % on contracts.

French Doctor Degrees.

There are three french doctors degrees a) Doctorat de troisième cycle b) Doctorat d'Etat and c) Doctorat d'Ingénieur. The first a) is a preparatory degree for b) and c) is a special degree for engineers.

2. IRIA

During my visit to IRIA the work done in the groups of Prof. Faurre and Prof. Yvon were discussed in some detail. I also had brief conversations with Prof. Lions and Dr. Glowinski

P. Faurre's group

The work was presented by S. Attasi, F. Germain and M. Clerget. The following areas were covered.

1. Realization theory for stationary Gauss Markov (G.M.) processes.

2. Realization theory for nonstationary G M processes.

3. Signal detection.

4. Digital image processing.

5. Nonlinear filtering.

The items 1 and 3 were discussed in some detail, the orther areas were covered superficially.

Realization Theory For Stationary G.M. Processes.

The object is to produce an internal description (a state model) of a G M process from the observation of a sample of the process. The problem can of course also be considered as an identification problem for time series. Once the internal description is available it can be used in many ways for example to construct predictors and filters. The path followed has been given by Faurre.

The main steps are the following: The covariance function $\Lambda(\tau)$ is estimated from the sample covariances. Applying algorithms for factorization of the Hankel matrix due to Ho and Rissanen, the minimal order and the matrices A and C in the representation

$$dx = Axdt + dv$$

$$dy = Cxdt + de$$

are determined. It then remains to determine the incremental covariance

$$Rdt = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} dt$$

of the Wiener process $\begin{pmatrix} v \\ e \end{pmatrix}$. A complete solution to this problem is given. The characterization is done via the positive real lemma. The results obtained give physical insight as well as algorithms. The analysis also unifies and extends several results in system theory for example, spectral factorization and multiple solutions to the steady state Riccati equation. The results covered both the discrete time case and the continuous time case. The results were also demonstrated using a hybrid installation, two noise generators, one analog computer TR 48 and one process computer T 2000. The stochastic process was generated by feeding white noise through a second order linear system, white noise was added to the output. The signal was sampled, converted and fed to the digital computer. The sample covariances were computed. The Hankel matrix was factorized and one representation of the incremental covariance computed. The signal was then filtered through the corresponding Kalman filter. The computations were carried out batch wise using 4000 points in each batch.

Digital Image Processing.

The basic idea behind this project was to construct two dimensional stochastic processes which admit linear recursive filtering. The following model was proposed

$$(*)\begin{cases} x_{k+1,\ell+1} = F_1 x_{k,\ell+1} + F_2 x_{k+1,\ell} - F_1 F_2 x_{k\ell} + V_{k,\ell} \\ y_{k,\ell} = H x_{k\ell} + e_{k,\ell} \end{cases}$$

where k and ℓ are the spatial indices $\{y_{k,\ell}\}$, the process $\{v_{k,\ell}\}$ and $\{e_{k,\ell}\}$ two dimensional white noises. The process represented by (*) has a two dimensional spectrum which can be factored although there is in general no square factorization. Recursive formula for the estimates can be determined.

Theoretical problems of the type: What is the most general two-dimensional G M process that admits a recursive filter? What are the limitations of the representation, will be discussed in a forth-coming report.

Application to digital image processing were planned a scanner for picture has been ordered.

The realization problem i.e. how to find a model (*) given a sample of the process have been studied along the same lines that were applied to the one dimensional problem.

References

/1/ P. Faurre: Réalisations Markoviennes de processus stationaires. Rapport de Recherche no 13, IRIA, mars 1973.

/2/ S. Attasi: Filtrage de processus à représentation Markovienne Poissonnienne". Rapport de Recherche no 18, IRIA, mai 1973.

/3/ S. Attasi: Systèmes linéaires homogènes à deux indices. Rapport de Recherche n° 31. IRIA, Sept 1973.

Yvon's group

Professor Yvon and his collaborators are concerned with optimal control of distributed parameter systems. So far they have studied computation of optimal control programs (open loop). During the past two years a number of partial differential equations originating from real problems have been investigated through collaboration with different external groups.

A considerable experience has been gathered in the areas of proving existence for particular problems, numerical solution for simulation and computation of optimal control strategies. In the future it was planned to compute feedback laws for distributed parameter systems by postulating a feedback law having a specified structure and optimizing a criterion with respect to the parameters of the given feedback law. Some examples were discussed in more detail namely

1. Heat Transfer Processes

   Control of an ingot furnace
   Cross flow heat exchanger

2. Membrane Processes

3. Gas Transportation

There are good documentation on all these problems in the references given in the end of this section.

Control of an Ingot Furnace.

A general model of a steel furnace was developed in collaboration with engineering groups. The model has as state-variables , the temperature of the ingots y_1, the wall-temperature y_2, which are all functions of time and a spatial variable and the gastemperature which was assumed constant. The study shows that classical functional analytical tools could be applied to established existence and uniqueness. I was also shown that the maximum principle for parabolic equations could be exploited to show that the ingut temperature is always less than the flame temperature. This could not be shown for the model initially used but after correcting a mistake in the model the result could be established. Thus proving that abstract mathematics can sometimes be very practical. The control problem was formulated as to find an oilflow such that the cost is minimal when the process is operated over a fixed time subject to the constraint that the maximum difference in temperature between two points in the ingot is less than a specified limit. The control strategy was parametrized thus reducing the optimization problem to a problem of minimizing a function of several variables with constraints.

The loss function were evaluated using difference approximations. The optimal control programs obtained were similar to the ones in actual use. The full details are found in the reference /2/, where calculations are given for an oven with a single ingot and for an oven with 12 ingots.

Cross Flow Heat Exchanger.

The cross flow heat exchanger was studied in collaboration with the analog - hybrid laboratory of C.N.R.S. (P. Malavard). The idea was to supplement the simulation studies done by the hybrid by optimization studies.

Identification Problems.

Yvon mentioned that they had encountered many identification problems in connection with the analyses of the practical problems. When the physical models were obtained it happened frequently that there were several parameters in the model which were poorly known. The coefficients for heat transfer between the wall and the liquid in the heat exchanger and the thermal diffusivity of the walls of the heat exchanger were mentioned as typical examples. Another very interesting identification problem occured in the steel oven where the heat flux through radiation is proportional to $T_{wall}(x) - T_{ingot}(\xi)$ and the coefficient of proportionality depends on the geometrical relations between the ingots and the walls.

References.

/1/ D. Leroy: Methodes humeriques en controle optimal application à un probleme d'échange thermique. Thesis Le Diplome de Docteur de 3e cycle a l'université Paris VI, 06 dezembre 1972.

/2/ J. Yvon: Controle optimal d'un four industriel. Rapport de Recherche no 22 juillet 1973.

3. ÉCOLE SUPÉRIEURE D'ÉLECTRICITÉ (E.S.E.)

École Supérieure D'électricité (E.S.E.) is a private university for electrical engineers in Paris. The director is Professor Blanc-Lapierre, wellknown for his book on stochastic control processes. I made a short visit to the Automatic Control Department, where I met Professor Viault, Mr Tanguy, Mr Corscis and Mr Zervos.

The school has a three years education leading up to the Diploma degree. In the third year, there are twelve specialities, two of which are automatic control and computer science. There are about 30 students in each specialication. The control group has a staff of about 30 people. The laboratory has sevo mechanism, laboratory processes, analog computers, and a Hewlett packard process control computer, at the moment without a disc.

Apart from the Diploma degree, the graduate program was recently initiated. There was a strong emphasis on practical aspects in the education. For example in automatic control 240 hours was spent on practical experiments. The students in automatic control also spent 150 hours on computer science. This being the case, it was difficult to perform a long range coherent research programs because of pressure from the contracts, it was sometimes necessary to undertake to do research in diverse areas. At the moment three projects were considered:

1. System identification
2. Models for evaporators
3. Heat exchangers

The identification project was supported through C.N.R.S.. The idea was to implement identification scheme based on measurements of impulse responses and use of Rissanen algorithms to obtain a process model. The scheme was currently implemented on the Hewlett Packard computer and demonstrations were given. The heat exchanger was under construction in the laboratory. The intention was to use the heat exchanger for identification and control experiments. The evaporator control project was with Westinghouse.

4. LABORATOIRE D'AUTOMATIQUE DE L'INSTITUT POLYTECHNIQUE DE GRENOBLE

General

The laboratory which is headed by professor Perret has about 30 researchers and twelve technicians and administrative personnel. About half of the research staff are supported by contracts. Seven are supported by the university and six by C.N.R.S.. The experience with the contracts, many of which have been administrative through the D.G.R.S.T have been very good. The group has in particular done a significant work in this manner concerning control of distillation columns.

The general impression that the collaboration between university and industries through the auspices of D.G.R.S.T. is an excellent tool to bridge the gap between theory and practice. During my visit I had the possibility to discuss with Foulard, Guerin, Binder, Bornard, Gille, David, El-Fattal, Maupasse.

Organization

The control group is divided into two subgroups, systems and large scale logical and sequential circuits. There are 17 people in the systems group and twelve people in the other group. In the systems group a lot of work has been devoted to control of distillation tower. The first contract was initiated in 1969, since then many contracts have been completed. Heat exchangers has also been investigated as well as other industrial processes. The circuit group has been concerned with trafic control and start up and sequencing of industrial processes. The Telemechanique lines of computers were originally developed within this group, Dr Pajus made his thesis on the design. This work was later transferred to a company which was aquired by telemechanique.

Research work

There is a progress report, reference /1/ which gives a good overview of the acitivities covering the last year. Some projects were discussed in a little bit more detail.

Distillation

The group had a first contract with NAPTHA CHEMIE. During the period 1965 - 1967, DDC control of a super fractionating column were solved. Control of a heavy steam cracking unit with a production of 150 000 tons per year has also been considered. This work involves static optimization, steady state regulation, identification of crackers and reactors, identification of nonlinear static models. Quite spectacular improvements were obtained in the initial phase. Increase in production of about 16 % were reported. The results were partially achieved from new sensors, better filtering and use of more exact models. Several contracts have since then been completed. In the second contract, the general improvement were in the range of 3 - 4 %. The last contract involves control of a big steam cracking unit with a production of 400 000 tons per year. There are many loops due to recycling and there are multivariable stability problems.

Other processes

The group has also been concerned with control of PVC production, control of biochemical engineering, processes for production of antibiotics. This involves optimization of batch processes, system identification and control. The group has also been working in close collaboration with CTP on control of paper machines. The group is now starting a contract to model the french economy. This is done with a contract with the Ministry of Finance.

Large scale logical and sequential circuits.

This group have been concerned with implementation of fix-wire sequential circuits using graph theory, testing of algorithms and machines, computer asissted design, and computer nets. A new process control language called PROCOL which has been developed under the support of D.G.R.S.T. has also been studied.

Pilot plants

The laboratory has excellent pilot plant facilities. The two distillation tower system is just being completed. This system will be hooked up to a Telemechanique computer. The system was extremely well instrumented with a lot of sensors and a lot of actuators.

In the laboratory I also saw modelling of heat exchanger. A thourough study of heat exchanger modelling has recently been completed by Gille, who did his thesis on this topic. He discussed the whole sequence of models ranging from distributed parameter system to very simple approximations and he have ranges for the validity of the different model.

Adaptive regulation

I also had a discussion with dr El-Fattah concerning sub-optimal dual control strategies.

References

Laboratoire D'Automatique de l'Institut Polytechnique de Grenoble (E.R.A. 155). Rapport d'activite Scientifique Période du 1er Juillet 1972 au 31 Juillet 1973.

French Egyptian Seminar, Interconnection Network between Computer Units. Ain Shams University Cairo 5/19-27 1973.

Reseau Matriciel D'Interconnexions Entre Organes de Calculateurs. Congres AFCET 72, Grenoble 6 - 9 Novembre 1972.

A Computer Algorithm for Suboptimal Adaptive Control. Y. M. El-Fattah, Laboratoire d'Automatique.

5. CENTRE D'ÉTUDES NUCLÉAIRES (LETI).

LETI is an abbreviation of Laboratoire d'Electronique et de Technologie de l'Informatique. The laboratory covers a wide range of topics, measurement and signal analysis, applied electron physics, microelectronics, material research, rapid nuclear instrumentation.

I visited Laboratoire Mesure Controle et Traitment Electronique, which has about 120 persons. My guide was M. Delcroix, who gave an overview of the activity at LETI. It was particularly interesting to notice that it was possible to do theoretical analysis and to convert the algorithms obtained into specialized hardware within the laboratory. After the general discussion we visited three groups.

Development of Correlators.

The group had significant experience in signal analysis. A sequence of correlators were developed on contract with Slumberger. These correlators often contained special microcircuits manufactured by the microelectronics group.

Signal Analysis.

M. Garderet gave a quick survey of his research in signal analysis.

Conversational Signal Analysis.

M. Allemand demonstrated a very flexible system based on a hardware correlator, an oscilloscope and an Intertechnique computer with appropriate software. Using a specially developed conversational language it was possible to display and alter signals, to do correlation, fourier transforms and other signal transformations.

The system could accept inputs and produce outputs in many different formats. In the summary a very flexible tool for research and education.

References

/1/ Le Laboratoire d'electronique et de technologie de l'informatique (LETI). Rapport d'activité 1972.

/2/ Slumberger, Corrélateur humérique, CNTR 1024.

/3/ Slumberger, Transformateur de Fourier Numerique TFN 1024.

/4/ Slumberger, Filtre actif variable FAB 148 - FAB 124.

/5/ Ph. Garderet and J. Max: Mesures des fonctions d'ambiquité pour l'identification de systèmes linéaires non homogènes. Note technique LETI/MCTE no 936.

/6/ Ph. Garderet and W. Kofman: Etude theorique et conception d'un ambiguimetre en temps reel. Note Technique LETI no 914.

6. TELEMECHANIQUE ELECTRIQUE.

Dr Jean Pajus gave a brief introduction to the development of the company. We toured the development laboratory and the factory. The visit ended by a review of the software development by the programming manager.

Generalities

The company Telemechanique was founded in 1924 and started to manufacture electronic contactors in modular form. The major part of the production, 80 %, is still electromechanical components. The rest of the production is motor control, numerically controlled machine tools and process computers. Process computers are developed and sold through the Department Informatique Industriel in Grenoble which now has about 500 persons employed.

Hardware

Dr Pajus is a student of professor Perret. His thesis consisted in the logical design of a process computer MAT 01. Production of this computer was taken up by a small company Morse which was subsequently acquired by Telemechanique which in 1969 announced the computer T 2000 a 20 bit machine as its successor. In 1970 a smaller version T 1000 was announced. A 16 bit machine appeared in 1971 and modern versions of the earlier machines T 2000/20 and T 2000/10 have also appeared. About 300 20bit machines and 100 16 bit machines have been delivered. The company has to compete both with CII and foreign vendors. A particular strength of the Telemechanique computers is their excellent properties to withstand tough environments.

Software

I found the software developments very interesting. All new software was written in a systems programming language (PL) of the Wirth type. The PL assembler was developed by an outside group with company participation. A flexible macroprocessor was also available as well as FORTRAN, PL and ASM compilers. Both batch operating systems and real time executives were developed as well as an Editor and a conversational language. The real time executive was in accordance with the Purdue University standard.

References.

/1/ T 1600 Computers Brochure and Introduction Manual.

/2/ Calculateur Industriel T 2000/10 & T 2000/20.

/3/ Manuel de presentation du Systeme LSE (Langage Symbolique d'Enseignement).

7. VISIT TO CENTRE TECHNIQUE DE L'INDUSTRIE DES PAPIERS, CARTONS ET CELLULOSES (CTP).

CTP is an applied research institute similar to STFI in Sweden. It employs about 200 persons of which 60 are research engineers. The institute has 5 departments pulp, paper, applied mathematics and technical assistance contracts and documentation. The institute has many pilot plants including a complete paper machine and a pilot of a new patented paper machine. During my visit I discussed with the applied mathematics group. I also toured the laboratory.

Applied mathematics group

The applied mathematics group is headed by Mr Ramaz. I discussed with him and his collaborators, Mr Wisbruch, Mr Lebau, Mr Sangraz, Mr Perron, Mr Bauguin and Mr Wincent.

The applied mathematics group has been working in applied mathematics and statistics which essentially is a support program for the other activities. There has been a consider. ably effort in process control and in industrial informatiques and instrumentation.

Process control

The process control activity covers paper machine control, pulp mill control and head-box control. In the paper machine control area control of basis weight and moisture content, colour control and optimization have been considered. The basis weight control problem has been solved both using single variable methods and multivariable control. On the pilot plant the results of the multivariable approach was better, because low consistency sensors were used. There were, however, some difficulties with the implementation of the multivariable approach in practice because of limitations on current process control languages.

8. ALSTHOM

Alsthom is a company that produces heavy electric equipment. Until recently the company did not have a research group. Such a group was created in Paris some years ago and was later moved to Grenoble. The research group maintains good relations with Professor Perret's group at the University and it has had a series of development contracts with D.G.R.S.T.. Dr Landau gave an overview of the current projects and outlined the historical development of the group. The following areas were covered. I had also an opportunity to have a brief discussion with Mr Róuxel, who was heading the research group.

1. Stochastic Computation
2. Statistical Analysis
3. New Regulators

Stochastic Computation

The idea behind this project was to represent a signal by a random signal whose mean value represents the value of the signal. The advantage with such a representation is that many operations like multiplication and coordinate transformations are easily realized simply by gating.

It is thus possible to do special signal treatment very cheaply. The theoretical basis for analysis of stochastic signal had been given. Implementation of various devices like A/D and D/A converters and polar to rectangular coordinate transformations were developed. These devices were demonstrated in the laboratory.

An american company, General Instruments, was manufacturing an A/D converter on a chip which had been developed. Specialized regulators were a potential application area for the stochastic computation technique.

Statistics

The statistics group was concerned with weather prediction. A contract for local short term (days) prediction of weather for airports had been successfully completed. The methods were analysed against data covering 20 years from the Geneva airport. A success score of over 75 % was obtained as compared with 65 % obtained by current practice. A new project for a medium term (10 days) prediction was in progress.

New Regulators

The group had early developed a regulator for control of processes with a long time delay of the Otto-Smith type. These regulators contained a time delay unit capable of producing time delays from 50 ms to 24 hours. The model used was first order + time delay. It was currently thought that it was possible to develop completely new types of regulators using present day theory and present day technology. Typical examples are regulators including state-feedback, observers, model reference and adaptive features. Substantial theoretical and experimental work had been done based on Landau's wellknown results on design of model reference adaptive controller through hyperstability.

Several regulators of these type have been implemented and tested. Electrical drives, being one of Alsthom's major products, was a potential area of application. A very interesting demonstration of adaptive control of a DC motor whose inertia load was switched on and off clearly demonstrated the superiority of the adaptive regulator as compared to a fixed gain PI regulator. The very quick state adaptation during a fraction of the step response time was impressive. The particular regulator used in this application was based on a model reference scheme with a first order model, a Luenberger observer, gain changing and gain computing curcuits. The regulator was implemented on a handful of small curcuitboards.

The theory of the regulators were discussed and several interesting analogs between different model reference schemes and different system identification schemes were noted.
Apart from theoretical analyses of the algorithms many engineering studies related to the simplification and implementation of the algorithm had also been performed.

One was currently looking for various applications including electric drives, basic oxygen furnaces, and adaptive control of machine tools. Several problems related to choice of a suitable technology were not yet decided. A new subgroup for classical process control was also being formed. The existence of such a group was expected to simplify the problem of finding applications.

References

/1/ I.D. Landau: Model Reference Adaptive Systems - A Survey (MRAS) - What is Possible and Why?, J. Dynamic Systems, Measurements and Control, ASME June 1972, 119 - 132.

/2/ I.D. Landau: A Survey of Model Reference Adaptive Techniques (Theory and Applications). Preprints IFAC 3rd Symposium on Sensitivity, Adaptivity and Optimality, ISCHIA, Italy 1973.

/3/ J.J. Hirsch & P. Pettie: Real-time Identification using Adaptive Discrete Model. Preprint IFAC ISCHIA, Italy 1973.

9. LABORATOIRE D'AUTOMATIQUE ET D'ANALYSE DES SYSTEMS (LAAS):

General

LAAS whose name was formerly Laboratoire d'Automatique et de ses Applications Spatials is one of C.N.R.S. own laboratories. It was established in 1967 by decision of the Director of the C.N.R.S.. The manager of the laboratory who employs about 200 persons is professor LaGasse. The laboratory has facilities in terms of a building well equipped laboratoreis and permanently employed researchers.

There are several reasons why C.N.R.S. creates a laboratory of its own. One reason is the desire to generate research in new fields and in interdisciplinary areas which are not sufficiently covered by universities. Laboratories are usually formed around existing teams of good research workers. In the case of LAAS it developed from research carried out at ENSEEIHT. The research was initially directed towards aerospace applications. As indicated by the recent change of the name the scope of the research have now been widened considerably.

The laboratory is financed to 60 % with grants from C.N.R.S. and 40 % of contracts with industry and public organization. Last year the laboratory had about 30 contracts of which 20 were directly with industry.

The work at the laboratory is governed by a steering committee ("Comité de Direction") composed of laboratory coworkers, representatives of C.N.R.S. and external persons. The steering committee meets at least once a year to evaluate the work done and to guide future work.

Facilities

During a short tour of the laboratory, I got an overview of the facilities with a floor space of 5000 m^2. Among the facilities I noticed a simulation center with an IBM 1130 and a terminal to an IBM 370/165 in Paris, two analog computers EAI 680 and EAI TR 48 which will later be connected to a MITRA 15. The laboratory has a complete line to manufacture microelectronics in silicon technology. Furthermore there are well equipped temperature and humidity stabilized rooms to analyse electronic components. The testing system was sophisticated. I saw for example complete systems for automatic identification of parameters in semiconductor models. The laboratory has close relations to semiconductor manufacturers and is often called upon to analyse properties of special components. The laboratory also had facilities for environmental testing (temperature, vacuum, vibration). There is a good report which gives more details of the laboratory and its facilities /1/.

Research Program and Organization

The research is carried out by teams who work on well defined projects. A description of the teams thus gives the complete research programs. There are currently 17 teams, 3 interteam operations and two support programs in measurements and instrumentation and simulation and dataprocessing. Several research teams working on related problems are gathered in groups.

There are currently four groups, control system desgin and analysis, modelization and optimization of complex systems, logic systems and electronic components. The following groups were of most interest to me

Nonlinear Mechanics (prof Mira)
Stability and Interconnected Systems (Abatut)
Dynamic Scheduling (Roubellat)
Stochastic Aspects of Control Systems (Aguilar Martin)
Automatic Control of Urban traffic (Giraud)
Hierarchial Control (Grateloup)
Direct Digital Control of Chemical Processes.

There are several of these projects that are of interest to us. In the time available there was enough time to discuss with all groups but the activity of some groups were discussed in more detail.

Digital techniques and electrical propulsion.

This group consist of about 15 persons. They worked originally on satellites stabilizations using small special purpose digital computers. The group has been concerned with four projects

1. The ASMODEE
2. Digital control of turbojets
3. Satellite stabilization
4. Electrical propulsion

The ASMODEE project is a family of minicomputers. They are designed specially for process control with a large emphasis on the application. The computer architecture is unique. It has a generalized bus structure which is much more general than for example the bus structure in PDP 11. A computer has been designed, implemented and tested in several applications. See ref /2/, /3/ and /4/.

Digital control of turbojets

The team has carried out a complete project concerning digital regulation of turbojets, covering all faces from modelling, parameter estimation, and system identification, determination of control, simulation mechanization using an ASMODEE prototype test both including ASMODEE prototype plus analog simulation as well as ASMODEE computer plus real turbomachines. It is interesting to see that the same group covers all the steps from conception of control system to implementation and manufacturing of the computer. The future plans of the group include design of ultra reliable minicomputers with good availability, failure, detection and reconfiguration. A project on complex system employing a federative structure was also considered.

Stochastic Control

The group of Aguilar Martin is concerned with different aspects of stochastic control theory, nonlinear filtering, system identification and stochastic control. I had the opportunity to discuss in detail with J. Aguilar Martin, G. Salut, G. Alengrin, E. Castell, Castan, A Fournié and C. Hernandez.

Nonlinear Filtering

Professor R. Bucy had visited the group for a year to participate in the research on nonlinear filtering. This work covers many aspects. Exact solution of the functional equations for the nonlinear filter, approximations and applications. A recent report ref /5/ gives a survey of some of the results. Among the applications considered were

- o estimation of reaction coefficients in a vinyl acetate reactor pilot plant
- o estimation of reactivity coefficients in a nuclear reactor
- o estimation of the inertia tensor of a satellite.

System Identification

Significant work were carried out in the area of system identification. Instrumental variable methods were investigated in a thesis by Banon. Multivariable system identification was considered by Hernandez. See ref /6/. The approach taken was to use instrumental variables on a multivariable regression model. Particular emphasis was given to the problem of model validation. This was carried out through analysis of whiteness of residuals and confidence intervals of the parameters. The analysis was applied to simulated data (Rosenbrock's second order system) and to an industrial thermal process.

Currently applications to identification of parameters in a polymerization unit were considered.

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10. CENTRE D'ÉTUDES ET DE RECHERCHES TOULOUSE.

General

C.E.R.T. is a nonprofit research organization which has close relations to ENSAE (Sup-Aero) with professor Pelegrin as manager. The origin was C.E.R.A. (Centre d'Etudes et de Recherches en Automatisem), which was created in 1962 by Gille and Pelegrin to ensure that ENSAE should have access to a staff of competent teachers active in research and with a good practical background. When ENSAE was transferred to Toulouse in 1968 CERA was reorganized to become CERT under the auspices of ONERA. Part of the original group did stay in Paris. The organization has grown rapidly and it does now employ about 300 persons, of which 200 - 250 are graduate engineers.

CERT is financed to about 80 % by contracts and 20 % grants. The contracts come from private industry, from public research organizations and from governemental agencies like DGRST (civil) and DRME (military). Many full professors at ENSAE do their research at CERT. All reserach engineers at CERT spend about 10 % of their time in teaching both at ENSAE and at other schools. Many students from ENSAE do their thesis projects at CERT and CERT has also taken on the responsibility to run some laboratories for ENSAE. CERT is also heavily involved in continued education. The concentration is on compact 1 - 2 week courses, sometimes a three week course split ut as 2 + 1. About 250 - 500 persons take these courses each year. It is attempted to make courses with small groups (about 20) and to try to keep costs down as far as possible. The experience with the courses have been very good both from the educational point of view and from the point of view of creating contacts with good problems and contracts. (We have on a very limited scale had the same experiences with the STF courses!). A list of courses given 1973 - -74 are found in reference /2/.

Organization

CERT is divided into 7 departments:

- Automatic Control	DERA	E. Daclin
- Informatics	DERI	Gallaire
- Microwaves	DERMO	Thourel
- Aerothermodynamics	DERAT	Michel
- Measurements	DERMES	Calvet
- Physics (will change to optics)	DERPHY	Laug
- Space Technology	DERTS	Berry

The Department of Automatic Control is the oldest and the biggest department.

A short tour of the laboratories indicated clearly that they were extremely well equipped. I saw for example at least 6 identical subsonic wind tunnels and many other examples of multiple equipment. (This will of course make tit possible to do very good and pedagogical experimental work well in synchronism with the lectures).

Department of Computer Science (DERI).

M. Gallaire surveyed the main projects in the area of computer science namely

Software

Measurement of activities in a large system using a small computer, with direct access to the memory of the big computer. Measurements made without overhead! Development of techniques for tailsafe recovery after failures.

New Computer Structures

Participation in development of a computernet (CYCLADES). Develop software which will enable the use of programs on other machines while executing on his own computer. Unique assignment languages (Each variable can only receive a value once during execution. Data driven execution. Good for parallel computing). System will be implemented on micro- or minicomputers.

Applications

Computer aided design. Objects described using ALGOL 68. Extended language needed. Databases and information retrieval. A flexible system which allows a posteriori extensions based on atoms and relations works nicely but has overhead.

Mathematics

Numerical analysis. Finite elements. Stochastic processes in continuous time.

The department used CII 1070 and CII 1020 on timesharing basis with terminals.

A study of the process control language PROCOL including an evaluation from the language point of view was recently completed.

Department of Automatic Control DERA E. Daclin.

The department of automatic control is the largest and oldest of the CERT departments. The manager is M. Eric Daclin. The department has a total budget of 3.2 Mfr of which an unusually high part, 95 %, is in contracts. The department has about 60 persons 10 of which are working towards a degree. Each year the department also receives 20-30 students from ENSAE who do a project for about three months (examensarbete). The fact that only a small percentage of the department members were working on a degree made it possible to take on short contracts with firm delivery dates. The group seemed to be remarkabely successful in bridging the gaps between theory and practice. The range of applications that the group had covered over the years is very wide, from satellite attitude control through control of slab reheating furnaces to complete process control and production planning for a beer factory. (More details will be given later). The general spirit of the work was to try to use existing theory and methods as far as possible and not to develop new theory. It was also a policy to try to run the department in such a way that the engineers could spend say 10 % on their own professional development.

Areas of Interest

The problems studied at DERA had their origin in typical aerospace applications like autopilots and satellite attitude control The areas of interest have, however, been widened considerably and they do now cover a very wide range of industrial process control and operations research problems. The possibility of technology transfer is an interesting aspect of the wide area of applications. The problems covered can be divided into four groups.

Control of Vehicles

Design of autopilots for aircraft, submarines and torpedoes and satellite attitude control. Systems have been studied extensively. Recently a contract with Regie Autonome des Transports Parisiens (RATP) on control of urbane transportation systems have been completed (Control based on wire in ground, stopping precision ± 30 cm). Digital on board computers are also studied).

On-line Process Control.

Many studies on process modelling and parameter estimation were carried out during 1965 - -70. (Cement plants and thermal boilers). The emphasis is now more directed towards on-line process control. In the end of this year a T 2000 will for example be put on-line in a slab reheating furnace.

Large Systems

There is a clear tendency to move towards the area of production planning, and problems related to operations research. Urban traffic control is studied jointly with LAAS. Movement of trains in the Paris Metro have been studied as well as air traffic control. Dynamic order allocation in a foundary and complete automation of a beer factory are also investigated.

The three areas mentioned above represent the major activity There are however, also projects which do not fit in the above cathegories. These are often nonconventional problems where the tools of control systems theory are used.

Miscellaneous

Radiotheraphy (Draw a picture of a tumor on a scope. A program will give good positions for injection needles). Automated design of logic and switching signals. (Similar to analog flow graph techniques). Dynamic modelling of cities (A small mining town in the south-west of France).

A detailed description of the projects are given in the activity report /3/.

Organization

DERA:s personnel is currently organized into 8 groups. The project leaders are listed below together with the main activities.

1. Delmas
   Stabilization and piloting of nuclear submarines. Optimization theory. Optimization of petrol drilling. Bridging gap OR - AC. Production planning of foundary and beer factory.

2. Fossard

Early work on adaptive autopilots 62 - 65, using methods similar to Emiljanov's and Utkin's variable structure systems and methods based on frequency domain determination of parameters (G.E.). Power plant control satellite stabilization. Multivariable systems (book!). Fossard's group is now working on hierarchial control. After initial efforts in "hierarchial computations" (decomposition of optimization problems) the major interest is now in air traffic control (curved glide path approach). Believes that hierarchial problems must develop through studies of special problem rather than abstract generalities à la Mesarovic. (Agree!). Other potential areas water, resource management and power systems.

3. Gauvrit

Control of slabreheating furnace described by PDE. (Large contract which will lead to implementation using T 2000). Satellite stabilization. Since the control of the slab reheating furnace is one project which will go on-line shortly, it will be described in some detail below.

4. Henry

Traffic control. Modelling and simulation of cars. Identification. Try to introduce simulation instead of costly road testing. Car security.

5. Labarrère

Identification of power plants 65 - 67. Inputs PRBS type Estimation of impulse response and spectral density. The system had 4 inputs and 6 outputs which led to a complex model (order 60). Wiener synthesis made. Model simplified considerably (10 order). Cement plant was studied later. It was not easy to transfer the techniques from the power study due to measurement problem. Signal processing. Extensive simulation studies. Control of tanker pumping at sea. Now interested in control of ferrite manufacturing and automatic high pressure foundary. Extensive experience in system identification. Current philosophy: Make experiments yourself. Simple tests simple model. Gradual increase in complexity if needed. Least squares often sufficient. Always use test signals.

6. LeLetty

Distributed parameter systems. Heat exchanger in aeroplanes. Computer aided design of microstrip line wave guides. Control of pilot in chem. eng. dept.

7. Blanchard

Switching circuits. Automatic Design. Sequencing for torpedo. Automatic driving of metro trains.

8. Bousquet

Application of automatic control in medicin. Radiotheraphie.

The department has a small electronics group (1 engineer + 2 technicians) and a large simulation facility consisting of an IBM 360/44 with an Applied Dynamics AD4. They also have two Telemechanique computers T 2000 and T 1600. The simulation facility is run on a self service basis.

During my visit I had the opportunity to discuss the work in some detail with M Daclin, Delmas, Fossard, Gauvrit, Labarrére, LeLetty and Le Maitre. In a general discussion on the future development of automatic control Mr Daclin emphasized a) the measurement problems in automatic control b) impact on soft sciences c) merging of Automatic Control Operations Research and Computer Science.

Control of Slab Reheating Furnaces.

Several projects have been carried out with industry during many years

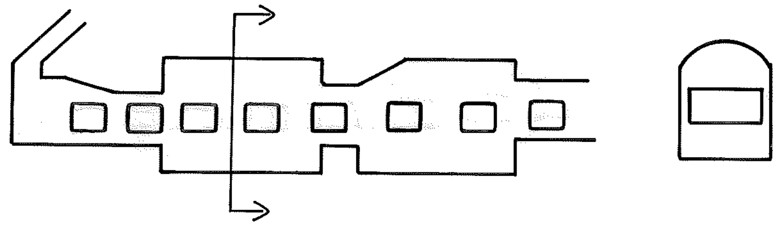
Modelling 1968 - 1969

A schematic picture of a furnace is given in the Figure below. The temperature in the slabs are modelled by heat equations.

$$\frac{\partial \theta}{\partial t} = \frac{1}{c\rho}\left[\frac{\partial}{\partial x}\lambda\frac{\partial \theta}{\partial x} + \frac{\partial}{\partial y}\lambda\frac{\partial \theta}{\partial y}\right]$$

$$\frac{\partial \theta}{\partial x} = k[T_f^4 - \theta_s^4]$$

$$\theta(x,0) = \theta_0$$



Identification

The parameters λ and c depend on temperature. Straight line approximations were made of the temperature dependence and the parameters were determined using nonlinear programming.

Optimization

The control problem can be formulated as a finite time control problem with the constraints

$$\max_x \; \theta(x,T) = \theta_1$$

$$\min_x \; \theta(x_1T) \geq \theta_2$$

where $\Theta_1 - \Theta_2 \sim 20^{\circ}C$.

Minimize the decarburization thickness

$$P_{\ell} = \int_0^t \max\ [0, (\Theta_s(t) - 750^{\circ})^2] dt$$

Two approaches were tried. Parametrize temperature distribution. Linearize the problem and solve for optimal profile. In the actual computations difference approximations were used. A slab was typically approximated by 10 x 10 points.

Realization

A T2000 computer will be put on-line in a Belgian factory charleroi.

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11. ECOLE NATIONAL SUPERIEURE DE L'AERONAUTIQUE ET DE L'ESPACE (ENSAE)

General

L'ecole Nationale Superieure de l'aeronautique et de l'espace is an institute of technology devoted to education of engineers in the aerospace and electronics area. ENSAE is administrated under the Ministry of Defence. The current director is professor Pelegrin (Ingénieur général) who is also manager of CERT.

Curriculae

The normal curiculum of ENSAE is a three year program leading to a diploma (similar to the swedish civ ing). The admission is restricted and there are severe entrance examinations. After the baccalauréat the students prepare for two years by studying mathematics in a lycée. An example of an entrance test is found in /1/. During the first year the students receive a basic science training with emphasis on mathematics, physics and mechanics. In the second year the students are oriented towards aircraft or missiles or towards avionics. In the third year the students can select one of three options, aircraft and missiles, avionics and automatic control and propulsion. A thesis of about three months full time work is also included in the last year (similar to an examensarbete at a swedish teknisk högskola). A complete list of the courses are given in /2/. Examples of thesis topics are found in /3/. The projects are done with research organizations like CNES or CERT or with industry.

There is also a post graduate one year course at ENSAE. This course can be chosen in four areas, automatic control, space and aerodynamics, computer science and systems. There are about 50 - 60 students in the post graduate courses. About 20 of these specialise in automatic control.

The yearly intake of students are about 100. It is also possible for foreign students to be admitted. The results are given in /4/.

Special Features

The school has many exceptional features. There are about 400 teachers for 350 students! Among the teachers about 15 are full professors while the others come from industry and CERT. The teachers coming from the outside are actively engaged in research and development work. (See comments under CERT!). The classes are small with a maximum of 20 students in each. In problem solving sessions (corresponding to övningar in Sweden) there are two assistants per 20 students. At least one of the assistants is mature and experienced. The scheme thus makes it possible to form and train new assistants. The laboratory facilities are excellent with good equipment and generally multiples of the same equipment to facilitate laboratory work in synchronism with lectures. There are well equipped lecture halls, many have close circuit televisions. During my visit I spoke with several of the professors Benzaken, Chvidchenko, Daclin, Delmas, Fossard, Labarrere, Le Letty. I had also an opportunity to visit some of the laboratories.

Laboratories

Aircraft

To make experiments in flight dynamics and control, the school has an aircraft Nord262 which is provided with an analog computer EAI 380 a Varian 620 and telecommunication to ground. It is for example possible to simulate certain manoeuvres on the analog computer and simultaneously follow the actual motions of the plane through appropriate sensors. The Varian computer is used to drive displays.

Automatic Control Laboratory

The automatic control laboratory has 6 analog computers EAI 380 with 4-channel strip recorders. There are also 6 AC/DC-servos manufactured for the school. The servos have a small breadboard and a box of electronics. In the laboratory there was also a new Varian 73 minicomputer and an Intel 8008 micro-computer set. It was intended to connect the minicomputer to the analog computers and to a mock-up of a cabin. The analog computing laboratory was used in regular laboratory courses but it was also possible for students to get access to the laboratory for problem solving.

The Mechanical Laboratory

In the mechanical laboratory there were devices like Wilberforce pendulums, coupled pendulums, beams, and gyroscopes. The experiments seemed interesting and thought provoking. Among the instrumentation I noticed devices for frictionless measuring angles and positions based on optics.

The Structural Laboratory

In the structural laboratory there were complete aëroplanes and parts thereoff to be used in vibration experiments. I met one student who was making a small airoplane for his own pleasure.

The ENSAE also have some laboratories with special and very expensive equipment which is run by CERT like a large enalog digital bybrid simulation facility and windtunels.

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