ASSOCIATION POUR LE DÉVELOPPEMENT DE L'ENSEIGNEMENT ET DE LA RECHERCHE EN SYSTÉMATIQUE APPLIQUÉE

MELISSA

Complete loop control : first study
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1. INTRODUCTION

The control of an artificial closed ecosystem is very complex. In order to facilitate its control, MELISSA has been conceived as 4 subsystems connected together. The control strategy is hierarchical. The upper level (level 2) consists in optimization of the global functioning of the loop. This optimization results in the determination of setpoints for all the compartments. The goal of level 1 is then to pilot each compartment in function of the setpoints sent by level 2. The respect of the actions calculated by level 1 is ensured by the level 0 of control.

This control strategy has induced the development of a control system.

Those developments, and choices of hardware and software have been done in a first time for Spirulina compartment control. They need to be progressively extended for the control of the global loop.

It will be done in UAB, by trying to keep the more of what has been previously developed.

The goal of this technical note is to specify the future development to be realized by UAB.

So, a description of the present global control system is done in chapter II. Then, the following chapters concern more precisely the Global Purpose System which is the programming interface of the control system. In chapter III, the present version of GPS programming is described, and in chapter IV, the future developments and extensions are specified.

2. CONTROL SYSTEM ARCHITECTURE

All the communications between the compartments and the control system are done through the level 0. Each compartment has its own level 0 which is composed of several basic controllers, and which realized the acquisition of data.

The controllers that have been chosen for the level 0 are P100 of Hartmann & Braun. They are managed by the control system MDC 100 of Industar, but they can be autonomous in case of misfunctioning of the upper level of control system.

The upper level of control system is actually composed of 3 units which are all PC's. Two of them are user stations.

- The control station deals with the controllers management and configurations, and with the process supervision. It is also the interface between the controllers and the rest of the control system. Its on line function is the process supervision and the interface with other PC's. It's off line function is the configuration of the MICON and of the system.

- The user station function is to observe the evolution of the process, and eventually to modify its functioning but the access are limited to a certain number of variables for security reasons.

- The Global Purpose Station (GPS) is a programming interface which allows to develop specific applications. The level 1 and 2 of the control strategy, with optimization and fault detection are or will be developed on this station.

The communication between the 3 stations is done through the network ARCNET.

The P100 controllers and the numerical extensions dedicated to the same compartment can communicate through an horizontal communication interface (a maximum of 32 P100).

The communication of all the controllers with the supervision (system station) is done through the vertical communication interface, realized with a vertical communication controller (VCC).

The other functional units of the control system are :

- The control function : supervision of the process, access to all the internal variable of the controllers.

- The centralized alarm management : to inform the user of misfunctioning.

- The visualization function : to plot the evolution of a group of variables, on a certain horizon.

- The archivage function : to store the selected variables with a constant sampling period (5 different sampling period can be selected (from 1 to 60 seconds). With a period of 1 minute, 100 variables can be stored during 8 days.

- The GPS programming interface : it allows the user to develop its own applications and extensions in C language (advanced control with internal model, signal treatment (filtering) ...).
  Those applications are developed on the GPS station, which dispose of access procedure to communicate with the system station. The functions of the GPS are described in the next chapter.

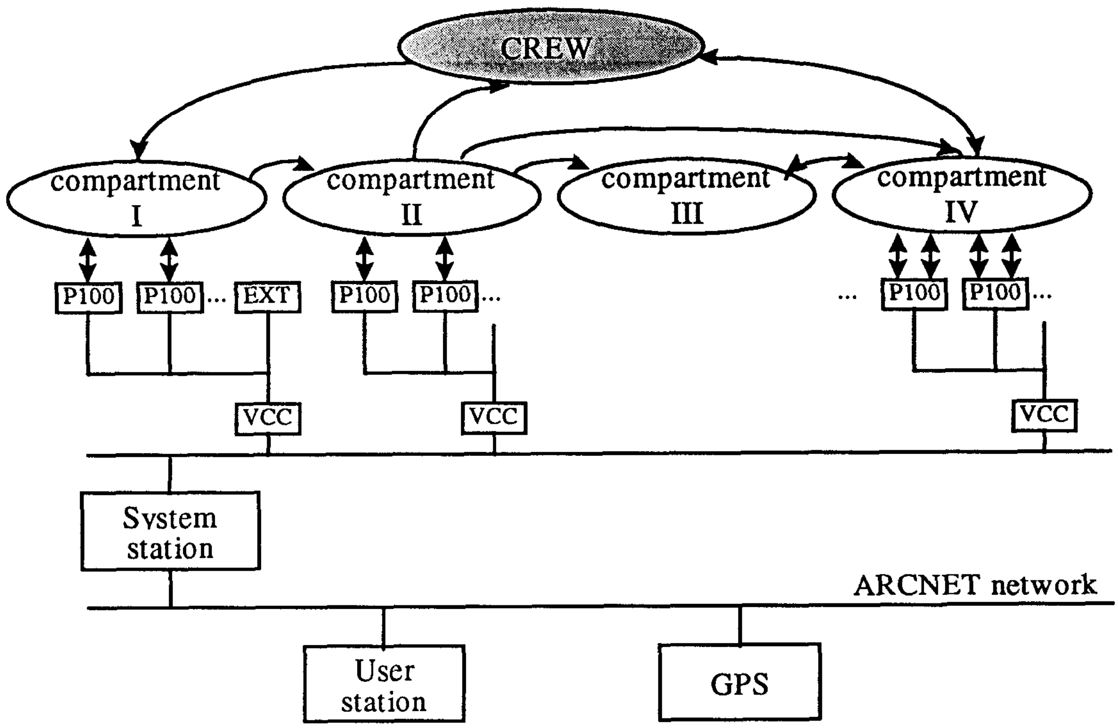


Figure 1 : Control system of MELISSA

3. GLOBAL PURPOSE STATION : PRESENT VERSION

The global purpose station (GPS) is the Industar programming interface. All the access procedures to the P100 controllers through the ARCNET network are furnished in a library and written in C language.

At that time, some developments and specific extensions have been written in C language. They have been developed for the control of Spirulina compartment, but in a modular form, to facilitate the extension to other compartments.

The program has been decomposed in 3 modules :

- a module of general management, including a user interface to visualize the control results and the state of the program ;
- a module of access to the controller data (which facilitates the use of GPS procedures) ;
- a module of control for Spirulina compartment.

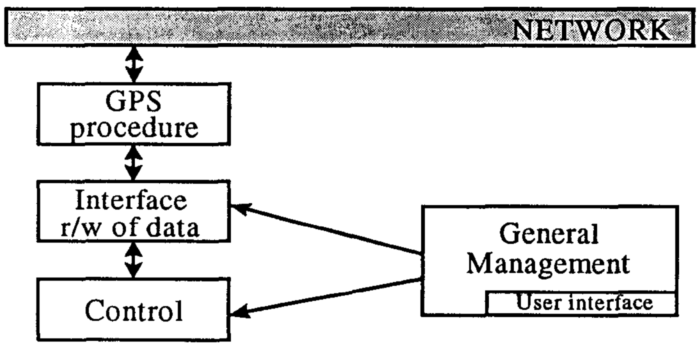


Figure 2 : GPS organigram

Hereafter, a description of the present software is done, in order to analyze more easily what are the necessary developments to extend this software for the other compartments, and progressively for the global control of the complete MELISSA loop.

3.1. General management

This part of the program is in charge of the management of all the tasks to be done.

At the beginning, all the initializations are done, and then all the tasks are sequenced with a time base of 1 minute. Those tasks are the alarm management, the network supervision, and the process control. They have been developed for Spirulina compartment, they will be extended for all other compartments.

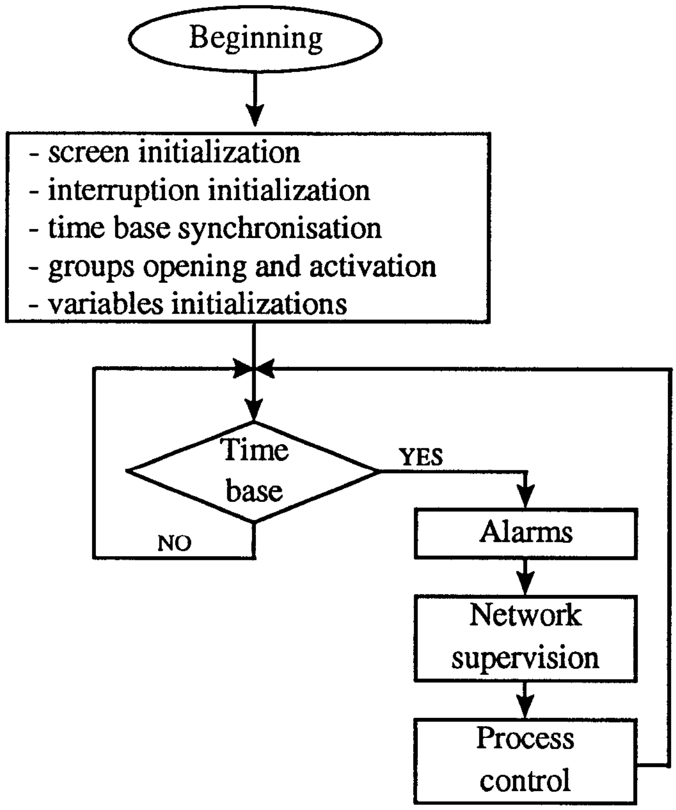


Figure 3 : General organigram

3.2. Screen initialization and management

During the running of the program, it is important to visualize some informations concerning the program state and the process evolution. The actual screen is represented on figure 4. It is separated in 2 areas, one for the results, one for the messages.

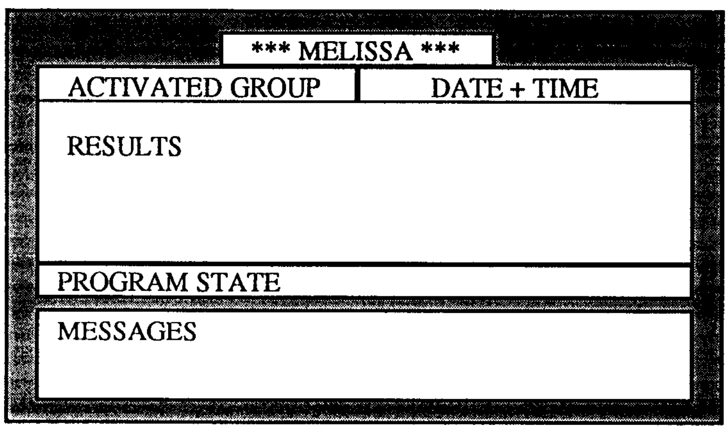


Figure 4 : Screen on GPS

The cursor is positioned by default in the MESSAGES window. So, at any time, a message can be written in this window with the subroutine *outtexte (texte)*. Specific procedures are used to write the informations in the good area. A special procedure allows to write an error message, and to activate a sound alarm when a misfunctioning is detected in the running of the program.

3.3. Program interruption

The program running can be interrupted with the use of a selected key. The interruption procedure which is activated allows either to stop the program, or to modify some parameters on line without stopping the program, for example to modify the value of a set point. In the first case (program terminated) it allows to modify an internal parameter, or to modify the software, and then to recompile the new software. In the second case (program not terminated), it allows to modify some functioning parameters on line. The parameters that can be modified on line are put in the free memory area of controllers (P100). Then, they are stored with the other variables.

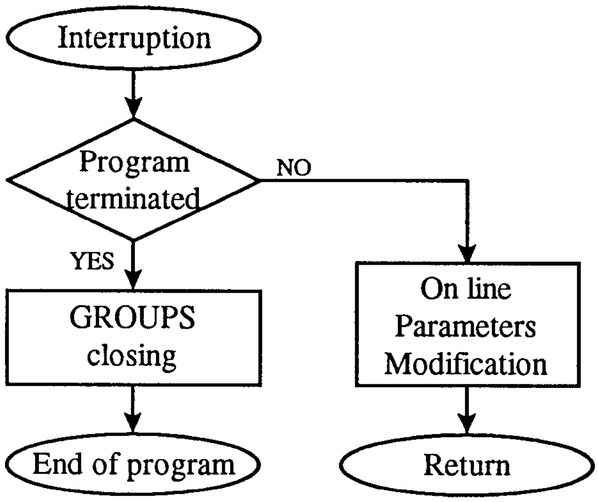


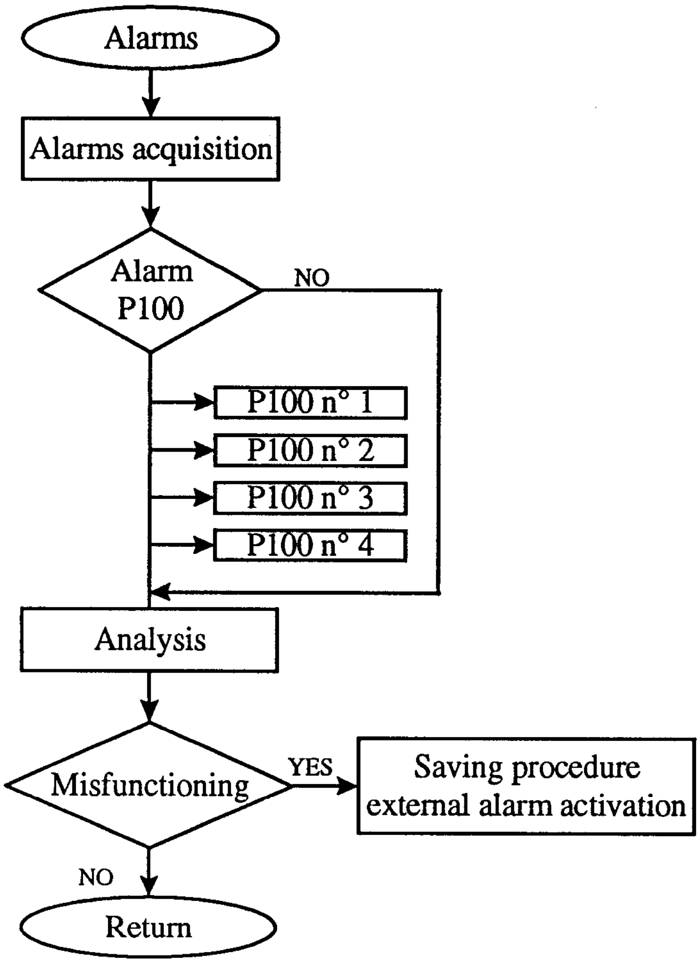
Figure 5 : Interruption procedure

3.4. Alarm management

MELISSA will have to function without any rest during several weeks, and several months. A detection of misfunctioning is necessary. A standard management of P100 alarms exists on the control system station, but it is not sufficient for such a complex ecosystem. A misfunctioning can be present in the compartment without any alarms on P100, and reversibly, an alarm on the P100 can have no significant consequence for the global control and the security of the process. So a specific «fault detection» has been elaborated. At that time, this program is very simple, and has to be completed with the future evolution of the studies and of the process design. Its goals are to :

– analyze the P100 alarms to stop eventually the program ;
– detect complex misfunctioning not detected by the P100 ;
– inform the user for an eventual intervention.

An external alarm can be activated.



3.5. Network supervision and error management

The network supervision is realized by a GPS function, which tests if the data contained in the mailing box are refreshed. If an error is detected when the program is running, different situations can be considered :

– the cause is known, and integrated in the normal execution of the program (ex : access to a data which is in a closed group) ;
– the error has a limited consequence, and is ignored. The procedure which has generated this error is reactivated, and the user informed (in the message window) ;
– the error has serious consequence. The program is stopped because it could not go on correctly.

3.6. Data management

The data accessible on the P100 controllers are of two different types : the «repere» (read only) and the «command» (read and write). To be accessible from the GPS, they have to be included in groups. Those groups can contain 40 variables and are constituted on the control system station. They can be treated by different GPS procedures (open_gr : to open a group ; activ_gr : to activate a group ; rd_gps : to read the specified «repere» ; set_cmd : to read the specified «command» ; wr_gps : to write a new value in the specified «command» ; close_gr : to close a group ; gettags : to get the name of a variable in a group ; garde : to verify the refreshing of the data in the mailing box.

Those procedures are not easy to use. In order to simplify the data management, an interface has been developed. The data are all represented by the same structure VARS. So, the access to those data are the same for all the types of data (read_var and write_var). The structure VARS contains different elements. Only one of them is specified by the user, with the following instruction :

sprintf(variable.name, «LOC_0125»).

It specifies the name of the variable in the program which corresponds to the system variable. The name of the system variable is specified in capital.

The other elements contained in the VARS structure (value, past values, min and max values, setpoint, unit, ...) are refreshed automatically with the reading procedure.

4. FUTURE DEVELOPMENTS AND EXTENSIONS

The control system developed for the Spirulina compartment will have to be extended for the control of other compartments. In this chapter, the specifications of those extensions will be presented.

4.1. Material architecture

The control system is well organized for an easy extension. The figure 1 represents the global architecture.

The system station can supervise the P100 (and extensions) controllers of all the compartments.

The different controllers of the same compartment can communicate through an horizontal communication. The communications between compartments are done through Vertical Communication Controllers and are managed by the system station.

The system station, the user station and the GPS are PC's, with DOS exploitation system. It will be sufficient for the global control of MELISSA, because the compartments can be considered as slow processes. The control periods are equal to several minutes.

In TN 28.3, concerning the global control of MELISSA, a functional analysis of the loop MELISSA has been presented, with a list of the measured variables, the controlled variables and the disturbance variables of each compartments. It allows us to dimension the control system. On each compartment, there are nearly 8 or 10 variables to control. We will reserve 8 P100 controllers for each compartment which corresponds to 16 loops. The loop variables can be reserved as following :

Spirulina compartment	: LOOP0001 to LOOP0016
Nitrifying compartment	: LOOP0017 to LOOP0032
Rhodobacter compartment	: LOOP0033 to LOOP0048
Liquefying compartment	: LOOP0049 to LOOP0064

4.2. Flow of data

The analysis of the global control of MELISSA (TN28.3) allows to quantify the flow of data between the stations and the compartments.

The P100 controllers deal with the level 0 of the control, and with the measure acquisition. The GPS deals with the level 1 and 2 of the control, and with the fault detection and global alarm management. So GPS needs to access to all the measured, and controlled variables. The main system variables will be put in a GPS group.

GPS groups will be named :

SPIRU01, SPIRU02, ...	for Spirulina compartment
NITRI01, NITRI02, ...	for nitrifying compartment
RHODO01, RHODO02, ...	for rhodobacter compartment
LIQUE01, LIQUE02, ...	for liquefying compartment
GLOBAL	for global control

The flow of data between the control system, and its programming interface GPS is important for two main reasons :

- on GPS, the level 1 and 2 of the control, the fault detection and global alarm management needs to access to many informations concerning the process : the measures, the alarms... The communication between the process and the GPS is done through the system station. All those measures and alarms are obtained on the P100 controllers and are transmitted to the GPS by the system station. On the other side, the setpoints calculated by the level 1 of the control are sent to the P100 controllers through the system station.

- on the control system, there are some functionalities (storage, alarms) that are very important for the safety and robustness of the system. So, it can be interesting to send on this control system, the main variables used on GPS (for example, the model output calculated in the model based control law) to have an automatic storage of those variables. Those variables will have to be put in LOC variables on the control system. we propose to reserve nearly 130 LOC variables for each compartment.

Micon1 : LOC_0109 to LOC_0172 and LOC_0209 to LOC_0272 for Spirulina compartment
Micon2 : LOC_0309 to LOC_0372 and LOC_0409 to LOC_0472 for Nitrifying compartment
Micon3 : LOC_0509 to LOC_0572 and LOC_0609 to LOC_0672 for Rhodobacter compartment
Micon4 : LOC_0709 to LOC_0772 and LOC_0809 to LOC_0872 for Liquefying compartment

4.3. GPS screen

In the actual version, the screen concerns only the Spirulina compartment. It will be necessary to define a screen for each compartment. A list of variables has to be selected to be visualized on the specific screen. This list will be composed of the more significant measured or controlled variables for each compartment. An additional screen concerning the global functioning of MELISSA loop will be defined, in order to visualize the main flows between the compartment and the main productions of the loop.

The system will be initialized on this global screen, and then, it will be possible to select on line the visualization of any compartment screen. The name of the considered compartment will be written on the screen. To change of screen, it will be necessary to come back to the global screen, and to select the new screen.

For each selected variable, the name, the value and the unit will be visualized on the screen. It will correspond to those defined in the VARS structure.

A maximum of 10 different variables for each compartment can be visualized on each screen. They will be chosen later. Those 10 variables will have to be declared in the same GPS group, because only one group can be activated at the same time (SPIRU01.GPS, NITRI01.GPS, RHODO01.GPS, LIQUE01.GPS and GLOBAL.GPS).

4.4. GPS main program

In the actual version, the main program is called Spirulin.c and concerns only the Spirulina compartment. It will be renamed melissa.c. This main program calls all the tasks to be realized for the global control of MELISSA. That is mainly the hierarchical process control (level 2 (global) and level 1 (for each compartment), but also the screen management, the interruption (and parameters modifications) management, the network supervision, the alarm management and eventually additional calculations.

The organigram of this main program is given in figure 7. The initialization part is the same as in the actual spirulin.c, except that the screen initialization concerns the global screen, and not the Spirulina compartment. The rest of the tasks are sequenced with a time base of one minute.

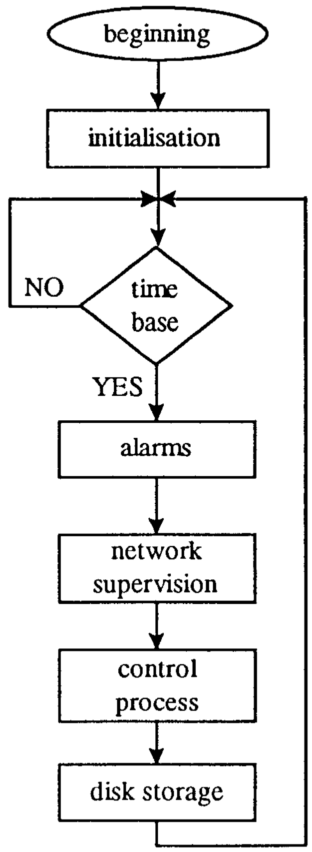


Figure 7 : Main program organigram

4.4.1. Process control

The process control will be composed of several routines : the global control (level 2) is firstly executed (control_global( )), and then the control for each compartment (level 1) are executed one after the other (control_spiru( ), control_nitri( ), control_rhodo( ), and control_lique( )), with the setpoints determinated by the global control (figure 8).

The control periods for the global control (level 2) and for the compartments control (level 1) can be different. The control period of level 2 is generally greater than the control period of level 1. All the more, the control period for the level 1 can be specific to each compartment.

For the Spirulina compartment, the level 1 has a period of 5 minutes. The value of the other control periods will be discussed later.

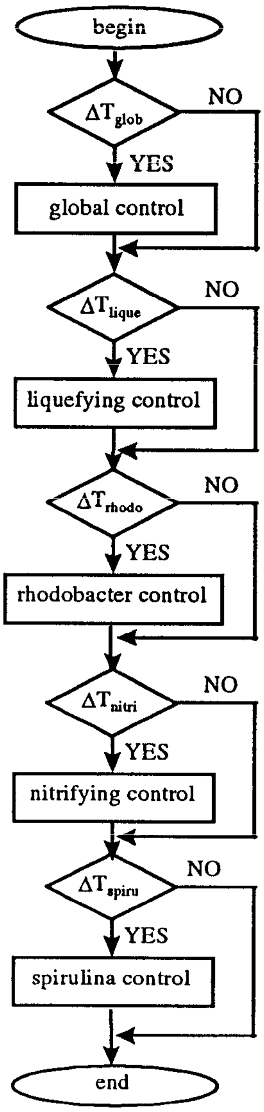


Figure 8 : Organigram of the control process

4.4.2. Alarm management - fault detection

To control such a complex system with a sufficient security, it is necessary to develop a fault detection algorithm. The P100 controllers and the control system dispose of local alarms. But it will be necessary to elaborate a global management of those alarms. Different approaches can be used to solve this problem. An approach based on model can be suggested to detect misfunctioning of the reactors, before reaching the alarm level, by comparing the model and the process. Those algorithms will be developed later.

In a first time, the alarm management will consists in replacing the routine alarm_spiru( ) by a general routine alarm_melissa( ), which will supervise all the compartments alarms.

4.4.3. Signal treatment

The GPS main functions are (or will be) :

- the level 1 and 2 of the process control ;
- the fault detection and alarm management.

They need measures. It can be interesting to develop some routines for signal treatment.

In the present version, different routines have been developed to calculate :

- the average of a variable during a time t
- the average-2 of a variable during a time t
- the variation of a variable during a time t
- the variation of a counter during a time t
- the slope of a variable during a time t
- the slope of a counter during a time t.

The structure and the name of internal variables of those routines will be modified if necessary, in order to be accessible for all the variables.

It can be interesting to develop other routines of signal treatment. For example a low-pass filter to eliminate the high frequency noise on the measure. This filter can be a first order filter :

$$s_f(n) = \alpha . s_f(n - 1) + (1 - \alpha) s(n - 1)$$

with $\alpha = \exp\left(-\frac{dt}{\tau}\right)$ τ : time constant of the filter

The cut frequency of this filter is :

$$f = \frac{1}{2\pi\tau} \qquad\qquad \xrightarrow{s} \boxed{\text{filter}} \xrightarrow{s_f}$$

4.4.4. Disk storage

On the control system, a storage procedure exists. 5 different storage periods from 1 to 60 seconds can be chosen. The selected variables must be put in storage groups. Actually the capacity of the control system allows to store nearly 100 variables during 8 days with a period of 1 minute, but it depends on the size of hard disk. It can be increased if necessary.

On the GPS, we can develop a routine of archivage on disk with greater periods. The storage frequencies will be chosen equal to the control frequencies. For the measured variables, the stored values will be the average of the measures during the control period. This will allow to have a longer storage of the main variables.

As for the control, the storage will be done with different frequencies in function of the considered compartment.

On the control system and on the GPS, the storage files are FIFO files which allows to have always the last stored variables, on a certain sliding horizon.

4.4.5. GPS declarations

General declarations for the main program on GPS are done in melissa.h. There are general structure declarations as GPS_FILE or VARS for the file and data management. There is also a specific structure declaration REACT for the state of the spirulina reactor. This will be renamed REACT_SPIRU, and other structure specific to each compartment REACT_NITRI, REACT_RHODO and REACT_LIQUE will be defined. Those structures are used in the control algorithms of each compartment. They represent the state of each compartment, used in the corresponding model.

Their elements will be chosen in the same time as the determination of the model used in the control algorithm. In all the structures, the following variables will be put :

the pressure (press_spiru, press_nitri, press_rhodo, press_lique)
the temperature (temp_spiru, temp _nitri, temp _rhodo, temp _lique)
the pH (pH_spiru, pH _nitri, pH _rhodo, pH _lique)

plus specific concentrations, and specific actions (light for the photosynthetic compartments ...).

5. CONCLUSION

The first developments realized on GPS for the spirulina compartment control can be considered as a good basis for the further developments. The material architecture was already designed for the complete loop control.

The material extensions will mainly consist in addition of MICON with P100 controllers and/or more powerful PC, and greater hard disks.

The soft extensions will mainly consist in a generalization of the routines developed for the spirulina compartment.

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ANNEX 1

COMPARTMENT I : Liquefying

• Measured variables

** : gas composition (chromatography) : H_2, VFA, CH_4
*** : flow of gas
*** : flow of liquid
* : urea
*** : temperature T
*** : pH
*** : total pressure P_T
** : redox potential pE
*** : dissolved O_2

(estim) : VFA (liquid)

• Actions

- exogen water flow
- output flow
- acid/base ($\rightarrow$ pH)
- valve ($\rightarrow P_T$)
- heater ($\rightarrow$ T)

• Controlled variables

- temperature T, total pressure P_T, pH
- dissolved O_2,
- volume, dilution rate
- NH_4^+, VFA/CO_2

COMPARTMENT II : Photosynthetic - Rhodobacter

• Measured variables

**	: gas composition
***	: flow of gas
***	: flow of liquid
***	: total pressure P_T
***	: temperature T
***	: pH
*	: urea
***	: biomass
**	: acetate, lactate
**	: NH_4^+
(estim)	: quality of biomass
**	: light

• Actions

- exogen water flow
- output flow
- incoming gas flow
- heater ($\rightarrow$T)
- light power ($\rightarrow$light)
- acid/base ($\rightarrow$pH)
- valve ($\rightarrow P_T$)

• Controlled variables

- temperature T, total pressure P_T, pH
- urea
- VFA
- biomass

• Disturbance variables

- liquid output of liquefying compartment (flow, composition)

COMPARTMENT III : *Nitrifying*

- Measured variables

***	: gas composition (O_2, CO_2)
***	: gas flow
***	: liquid flow
**	: NH_4^+
**	: NO_3^-
(estim)	: NO_2^-
***	: temperature T
***	: pH
***	: total pressure P_T
***	: dissolved O_2
(estim)	: biomass

- Actions

- exogen water flow
- exogen O2 flow
- output flow
- heater ($\rightarrow$T)
- acid/base ($\rightarrow$pH)
- valve ($\rightarrow P_T$)

- Controlled variables

- temperature T, pH, total pressure P_T
- volume, dilution rate
- dissolved O_2
- NH_4^+, NO_3^-, NO_2^-

- Disturbance variables

- liquid output of rhodobacter compartment (VFA, NH_4^+, urea)

COMPARTMENT IV : Photosynthetic - Spirulina

• Measured variables

**	: gas composition (O_2, CO_2)
***	: flow of gas
***	: total pressure P_T
***	: temperature T
***	: pH
**	: light (Eb)
***	: dissolved O_2
***	: level
***	: output liquid flow
**	: biomass
(estim)	: biomass quality
**	: NO_3^-
(estim)	: dissolved CO_2

• Actions

- exogen water flow
- output flow
- light power
- heater ($\rightarrow$T)
- incoming flow of CO_2

• Controlled variables

- temperature T, pH, total pressure P_T
- volume, dilution rate
- biomass
- dissolved CO_2

• Disturbance variables

- liquid output of nitrifying compartment (flow, NO_3^-)