# A robust control system for the new 1.2-m telescopes of the Geneva Observatory

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**ABSTRACT**

The Geneva Observatory has built two new 1.2-meter twin telescopes, one of them already operating in Chile since May 1998. The second prototype will be installed at the end of the year 2000 on the Canary Island La Palma (Spain). The technological complexity of these alt-azimuthal telescopes, as well as the operational constraints (an observer should be able to command on his own the whole infrastructure) required a control system taking care of all observation tasks, similar to the ones mounted on much larger telescopes.

This paper presents the hardware and the distributed software architecture of this 1.2-meter telescope control system, entirely designed and built by the Geneva Observatory. The modular concept and the choices of hardware tested in industrial automation made it possible to obtain great operational robustness and guarantee for long-term maintenance. The adopted solution is based on a transputer tree-network. The interactions between telescope and observer are transparent and completely integrated in the observation software of the attached instrument.

**Keywords:** telescope control system, real time control, servo-control, distributed architecture, transputer

## 1. INTRODUCTION

### 1.1 The T120 project

In the early 90's, the Geneva Observatory (Switzerland), associated with the Institute of Astronomy of the Leuven Catholic University (Belgium), decided to build two twin alt-azimuthal 1.2-meter telescopes. The engagement of the Swiss and Belgian institutes in this T120 project was motivated by the need of performing observation instruments to develop their scientific programs requiring intensive time-consuming observations. The major benefits the scientists of both institutes gained with their 1.2-m telescopes entirely consecrated to their research activities, are:

- frequent and regular sampling of the objects observation;
- a stable instrumentation (no time-waste for the mounting/unmounting of devices);
- a sophisticated instrumental calibration affecting directly the precision.

The Swiss station would be installed in the southern hemisphere on the ESO site of La Silla (Chile) and the Belgian in the northern hemisphere on the Canary Island La Palma (Spain). The austral telescope is in use since May 1998 with a *high-resolution spectrograph*. The other foreseen instruments are an imaging and photometry CCD-camera installed on a field rotator of both telescopes and the *photo-electrical photometry* on the field-rotator of the boreal unit.

In order to keep the complete technical know-how in a view of a long-term maintenance for both proprietary institutes, the construction of these telescopes has been assumed by the technical division of the Geneva Observatory, which has the operational capability and well-tried skills since several decades in the construction of spatial and astronomical instrumentation. Thus, the whole engineering and manufacturing of the major parts were executed in its offices and workshops. Only the heavy mechanics and the optics were sub-contracted. A dome was set up beside the workshops for the assembly and in-house test.

### 1.2 Technical management

So far, the Geneva Observatory has always internally mastered the development cycle of its instruments from the design to the assembly and tests. This was done mainly to establish proper technical know-how in order to offer an efficient long term maintenance. But this huge project of telescope construction was of a higher order of complexity compared to what had been done before. It required a great effort from the technical staff to integrate technologies in many fields like mechanics, pneumatics, hydraulics, optics, electronics, electromechanics, computers, etc. The size of this project overtook the available manpower, composed of 10 engineers and 15 technicians. Thus, a pragmatic approach had been followed: go on the market and use as much as possible devices suitable for our application avoiding so to reinvent the wheel. This had a significant impact on the control system design whose main function became so to merge the most heterogeneous devices in a robust, coherent and compact system. Obviously, this solution is a compromise between the performances and the long term services of the maintenance and the reliability. A particular attention had also been put in the avoidance of obsolescence by a deep comprehension of the functionning of the used devices and by obtaining full technical documentation from the vendors.

## 2. THE HARDWARE

### 2.1 Design constraints

The design of the control system had to fit the new observatory concept which had been also developed for the T120 project (see [1]). The main requirements influencing the structure of the control system were:

- a distributed architecture: the observation software running on a UNIX server takes care of the operational synchronization and the accesses to the telescope and the instrumentation via a Local Control Unit (LCU) under UNIX or Linux. Each instrument, and the telescope too, must be connected to the main system via an unique entry point, the dedicated LCU, which decouples and interfaces the hardware controller of the each instrument with the observation system;
- a single operator: the whole facility should be able to be operated by one single person, who has not necessarily to be an astronomer. Moreover, certain observations can be automated without requiring a permanent presence of the operator continuously during the night. It implies that all telescope operations must be fully automated;
- no support: no technical staff is available permanently on the site. This means that the telescope control has to be highly reliable. In addition, the maintenance and the failure diagnostic must be done remotely from the support centre in Geneva. In order to allow this, every telescope device must be accessible through the control system.

The general concept of the T120 observation system has been obtained by the physical division in sub-systems corresponding to the instruments. In the same manner, the control system of the telescopes has been designed as a distributed system composed of sub-systems, executing functional tasks such as:

- the axes control: pointing and tracking of the azimuth, elevation and field rotation axes of the telescopes. This is the only sub-system requiring a real time controlled processes. In a maintenance mode, the axes can be positioned independently;
- the mirrors control: the telescopes optics is a classical Ritchey-Chretien combination. The secondary mirror M2 is motorized on 5 degrees of freedom so as to allow on-line optics tunings before every observation. The primary mirror is supported with dorsal and radial pneumatic pads. A regulator ensures the uniform repartition of the pressure for all elevation positions. Different temperature sensors placed along the optical path are also connected to this sub-system;
- the control of the peripherals: this section will later be named ‘‘services’’. It manages the working of the 2 ground-based systems. The most important of these is the dome rotation and aperture. The second one is the hydraulic circuit of the azimuth hydrostatic bearing which also requires an active control: the oil pressure of the circuit must be adjusted in function of the oil temperature.

It is important to notice that these 3 groups must physically be separated since they have effectively no functional interactions and especially because their integration in the control system may occur independently during the development phase. According to what has been stated above, the hardware architecture of the 1.2-m telescopes control system can be outlined as in Fig. 2.1.

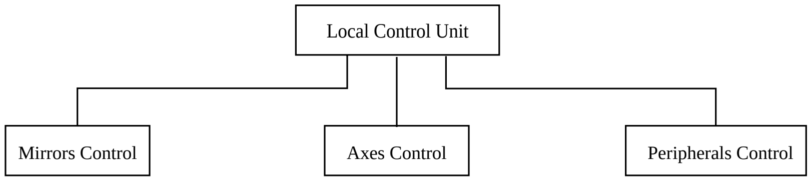



*Figure 2.1: Primary coarse modular layout of the telescope control*

The building design imposed also a strong constraint on the system control architecture. The telescope-LCU must be located in a computer room, 30-m away from the embedded sub-system of the mirrors and axes control. The ground sub-system of the peripherals control is set-up in another room at a of 20-m distance (in the hydraulic pumps room, see Fig. 2.2). The devices to handle are 15 motors and actuators, 11 servo-amplifiers and digital amplifiers, 14 position encoders, 75 digital signals and 18 analog sensors.

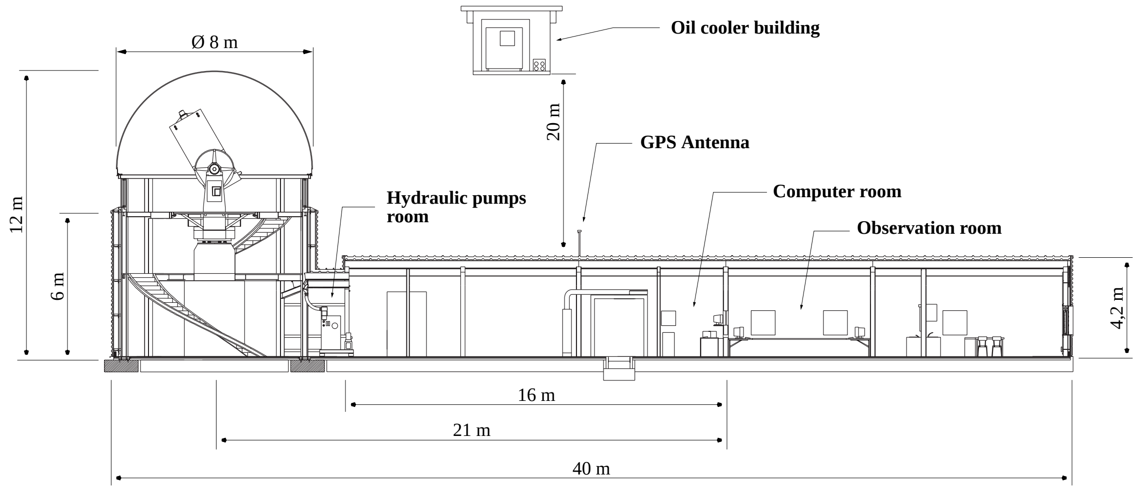



*Figure 2.2: Infrastructure view*

## 2.2 A transputer network architecture

At the end of the 80's, a new type of microprocessor appeared on the market , being most interesting for the control of astronomical instruments [2]: the *transputer*. This new VLSI microcircuit gathered all the functionalities of a microcomputer at the chip level: memory, processor, interconnection and communication. The integration of 4 communication links (max. speed: 20 MBits/s) permits easy point-to-point connections between processors. The conjunction of these fast links with the on-chip integrated timers provides a powerful tool to solve problems of parallel task synchronization directly by the component.

It also allows the programmer not need to care about the mechanisms of task synchronization related to parallel systems, and we know that this subject is a major trouble source in the multiprocessor systems implementation. The nice features described above fitted perfectly to the distributed control system needs of our telescopes. The setting of several transputers dedicated to limited tasks in a concurrent network made it possible to break free from the problems of real time synchronization and to ease the design.

The general guide lines for the realization of the control system having been defined, the use of a transputer network for the control of this installation still required two essential hardware interfaces:

1. An entrance point which carries out the connection between the system of observation running on SUN UNIX machines and the transputer network of the control system. Two solutions had been found. The first was a SBUS interface board and the second, which gives more compatibility guarantees, was a transputer-SCSI adapter.

2. Electronics that ensure the control of a sub-system by a transputer-master via a standard industrial bus, i.e. a "transputer-industrial bus" adapter. In 1992, the company GESPAC marketed the interface board GESPPU-1 at the format simple Europe giving access to its proprietary G-96 industrial bus by a transputer. Initially conceived as an accelerating card for PC or OS-9 systems, its use became immediately essential for our application as master-board controlling the slaves-I/O boards of the G-96 bus of the most several types: serial communication, incremental counting, TTL and industrial digital I/Os, A/D conversion.

Now that the two types of basic units of construction of the transputer network are defined, we can build its structure according to the basis of the draft of Fig. 2.1. The command system is divided in autonomous subsets, each of them controlled by a transputer connected with the others by its links. The network has an arborescent form starting from a *root* sub-system which is the entrance point. The links form the branches and the transputers are the points of ramifications. Fig. 2.3 represents this structure such as it was carried out for the control of the telescopes of 120 cm. The evolution compared to the previous structure of Fig. 2.1 is that the axes controller has been splitted in 4 modules to decouple the hardware of each one. Thus, the network is now composed of 7 top-bottom hierarchically inter-connected sub-systems.

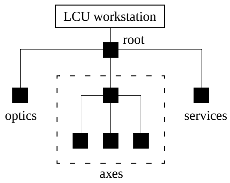



*Figure 2.3: The tree transputer network of the control system*

The applied principle for the network design is that each processor of the network should manage independently a control task by controlling itself the most heterogeneous devices. The essential functionalities performed by the control system are: the positioning and tracking of the telescope; the dome positioning, the positioning of the secondary mirror with 5 freedom degrees, the command of the telescope peripheral elements, and the state monitoring of the whole unit.

### 2.3 The sub-systems

The transputer network of Fig. 2.3 with all the devices attached to each sub-system is shown in details on Fig. 2.4.

The sub-system DISPATCHER is the entrance point into the transputer network. It is interfaced to the local control unit (SUN workstation) by the SBUS bus. Its only function is to ensure the physical communication between the control device of the telescope and the system of observation connected to the data-processing network of the infrastructure. It acts as a router of the requests towards the corresponding sub-system. Its link 0 is dedicated to communication by the host workstation, while the 3 other links are connected to the first ramification of the subsets KINEMATICS, OPTICS and SERVICES. All the other subsets have a physical interaction with their devices to control; thus, they require an interface with the industrial bus. The GESPPU-1 boards behave as master of their local industrial bus, by which they control apparatuses connected to the interface boards. The type of interface boards present in the bus G-96 corresponds to the specific needs of each sub-system. The subset KINEMATICS is the synchronizer of the axes movement of the telescope. It manages the reference of time and carries out the kinematics calculations of the telescope. However it does not interact directly with the drives of the axes. Its first link is connected to the DISPATCHER, while 3 remaining links make it by a happy coincidence possible, to connect it to 3 sub-systems corresponding to the 3 possible degrees of freedom of an alt-azimuth telescope: the angles of azimuth, elevation and field rotation. The subsets AZIMUTH, ALTITUDE and ROTATION deal with the management of the drive hardware (motorization and position coding) of the 3 telescope axes. In maintenance mode, the various elements connected to these sub-systems are directly accessed through the transputer network without passing by the intermediary of KINEMATICS. On the other hand, in observation mode, the synchronization predispositions of the transputers are fully used. The KINEMATICS deals with all the requests regarding the telescope tracking coming from the observation system and takes care of the real time control of the axes displacement. For more details see [3].

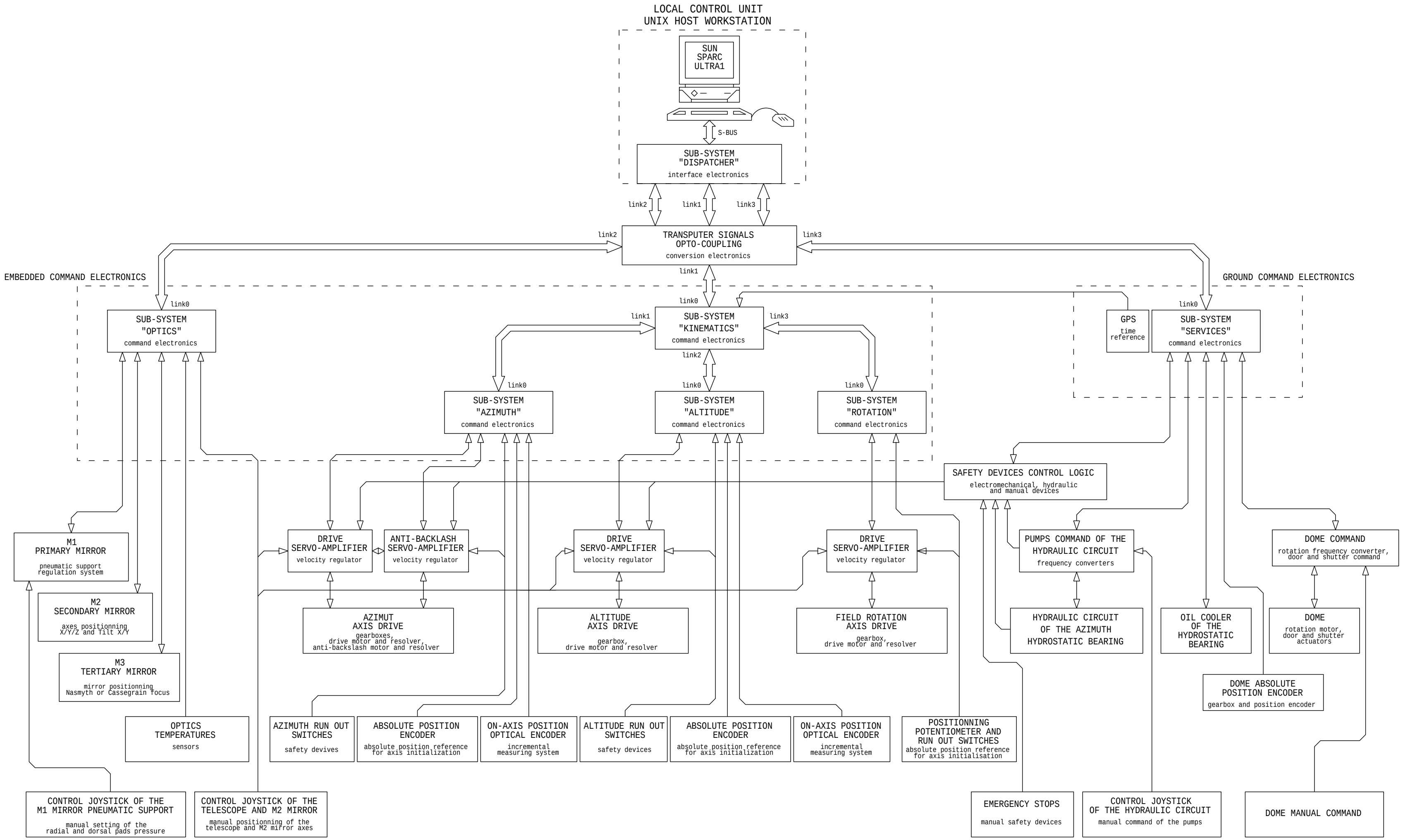



*Figure 2.4: Hardware synopsis*

The OPTICS sub-system controls the hardware of the 3 mirrors of the telescope, i.e. the dialogue with the pneumatic regulation system of the primary mirror M1, the positioning of the mirrors M2 and M3. Incidentally, the temperature sensors laid out on the telescope are also connected there. The SERVICES sub-system manages the telescope periphery, i.e. the opening and the rotation of the dome, as well as the control of the hydrostatic bearing.

The complete architecture of the transputer network based control system, including details of the components attached to each sub-system is represented on Fig. 2.4. Note that a manual remote controller has been provided for all relevant functional units, i.e. the pneumatic support of the primary mirror, the positioning of the secondary mirror, the telescopes axes, the hydraulic pumps and the dome. The manual command shunts the control system and permits maintenance interventions without need to have the electronics functioning.

## 3. THE SOFTWARE CONTROLLER

### 3.1 The observation system of the Geneva Observatory

The observation system, developed at the Geneva Observatory for the T120 project, is based on a client-server architecture running on UNIX machines of the LAN observatory network [1]. The telescope controller is bridged to the observation software following the same scheme as the others instrument controllers of the Geneva Observatory System (Fig. 3.1).

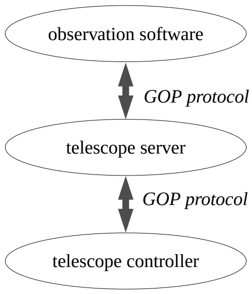



*Figure 3.1: client-server architecture of the telescope controller*

The telescope controller acts as a server's client. The server running on the LCU (Unix machine) decouples the controller (transputer world) from the observation software (Unix world). The communications between these units complies with a generic communication protocol: the *GOP* (Geneva Observatory Protocol) dedicated to the passing of inter-processes messages in a multi-machines, multi-protocols and client-server scheme. For more details see [1].

The server has mainly a routing function, doing no processing. It takes care of the transmission of command messages, generated by the observation software, to the telescope controller. These messages are already formatted at the upper level in plain ASCII text. A command message is formed with the command name, the address of the sub-system where the command has to be executed, and the execution parameters of the command. The reception process of commands at the controller entrance decodes this message which is then encoded in the internal controller protocol and routed to its destination address, i.e. a transputer of a sub-system on Fig. 2.4. After execution completion, the response is sent to the server by the process which has executed it. This answer message exits from the controller in plain text too. The server transmits it to the generator program of the observation program. If the request was a status monitoring demand, then the answer is directed to the status manager where approximately 500 status variables are maintained

### 3.2 The controller processes

The transputer is the material reflection of the concepts suggested by Occam, the programming language of the controller turning on the network of 7 transputers. The Occam language combines a high degree of abstraction suitable for a high-level language, like parallel processes handling and inter-processes communications management as well as the effectiveness of an assembler low level language. This software and hardware duality makes null and void the use of the traditional layer of an operational system in the programming of this type of system. However, the absence of a real operating system makes the processes vulnerable to deadlocks, particularly the inter-processes communication deadlocks. The integrity of communications, which is normally ensured by the operational system, is not guaranteed any more. It thus falls to the system designer to take care of that by adopting a judicious configuration of processes and by installing the software mechanisms of protection against communication blockings. This constrained strongly the design of the software controller of the telescope and constitutes the single difficult aspect in the software development of the system presented here. But once these problems have been resolved, the reliability and the software stability of all the units are incomparable. The Occam code is downloaded by the root of the network which, as already mentioned, does not require any OS and is concurrently executed on the 7 processors. During two years of intensive exploitation no failures or stops caused by the software had occurred. Its robustness represents indisputably the great strength of a distributed system developed on a transputer architecture.

The network of the telescope control is made of 25 processes being concurrently executed in the 7 processors. The processes are connected by software channels respecting 8 different communication protocols. We do not want to present here in detail the functioning, but only outline the general principles (details in [3]):

- 2 processes manage the communication with the server and the coding/decoding of the commands/responses;
- Only 1 process per sub-system, consequently 7 on the whole, has access to the I/O boards of the G-96 bus. This same process is able to accept the execution of hardware control commands coming from the observation software (*external command*) and to execute in parallel any permanent specific task of the sub-system. For example, the control of the axes for the processors of the axes controllers or the control of the hydraulic pumps rotation for the processor SERVICES. During the execution of an external command or a permanent task, a state monitoring of the telescope is performed continuously and stored in each sub-system. The results are returned to the state monitor once the observation software emits the corresponding request. These same processes of execution also allow having access to the whole hardware connected to the sub-systems. A main effort of implementation has been made in order to run the specific functions of the connected devices via external commands. Thus it is possible to program new functionalities by writing scripts easily at the observation software level. In this case, the whole controller is seen by the programmer like an access interface to the hardware;
- The other 16 concurrent processes running on the network are routing processes of requests. As each sub-system executes tasks independently and/or transmits messages on the communication channels in an asynchronous way, a rather complex mechanism of arbitration has been implemented in order to avoid the network blocking by message collision.

## 4. THE AXES CONTROLLER

### 4.1 Working principle

The axes control of the telescope is a sub-network of the controller. It is formed by the master-processor KINEMATICS to which the 3 slave sub-systems of the 3 axes AZIMUTH, ALTITUDE and ROTATION are connected (Fig. 4.1). It constitutes obviously the core of the control system. It functions according to following principles:

- Real time calculation of the axe kinematics of the telescope is performed by the permanent task running on the KINEMATICS sub-system. The sidereal time is maintained by the internal timer of the transputer. The time synchronization is carried out by the signal of reference delivered by a GPS. Then the kinematics setpoints are calculated: transformations of co-ordinates with corrections of atmospheric refraction and pointing model (P.T. Wallace method);
- The motion synchronization of the telescope axes is ensured by the master-processor KINEMATICS using the intrinsic mechanisms from synchronization of the transputer and Occam. The master transmits in a synchronous way the co-ordinates to the subsets controlling the drive of the axes through the transputer links. On a software level, these links are associated to the Occam communication channels by which the concurrent processes communicate. In other words, the instructions are generated by the permanent task running on the master of the KINEMATICS and are then transmitted by internal requests to the slave-processes which control the axes drives. The slave-processes get velocity commands for the axes and execute them on the motors returning the corresponding results for each request;
- The velocity control is not assumed by a permanent task of the sub-systems themselves, but lower at the device level, by an industrial servo-amplifier, which is connected to each of them. The axes motors of the telescope are commanded by velocity settings through them;
- The regulation in position of the axes is carried out by the permanent task in the 3 slave-processes controlling the axes. The position feedback is provided by an incremental encoder on the azimuth and elevation axes. For the field rotation, the position encoder is placed on the drive motor shaft.

When the kinematics co-ordinates are ready for their transmission, the calculation task carries out an *internal request* towards the 3 axe controllers. The synchronization of the requests towards each axis is carried out implicitly in the transputer/occam architecture. The arithmetic operations are followed by several transactions on the inter-processes channels, state monitorings, the parallel transmission of the internal requests, the hardware accesses and finally the recovery of the answers of each axes. This allows a sampling frequency of the axes velocity of approximately 50 Hz.

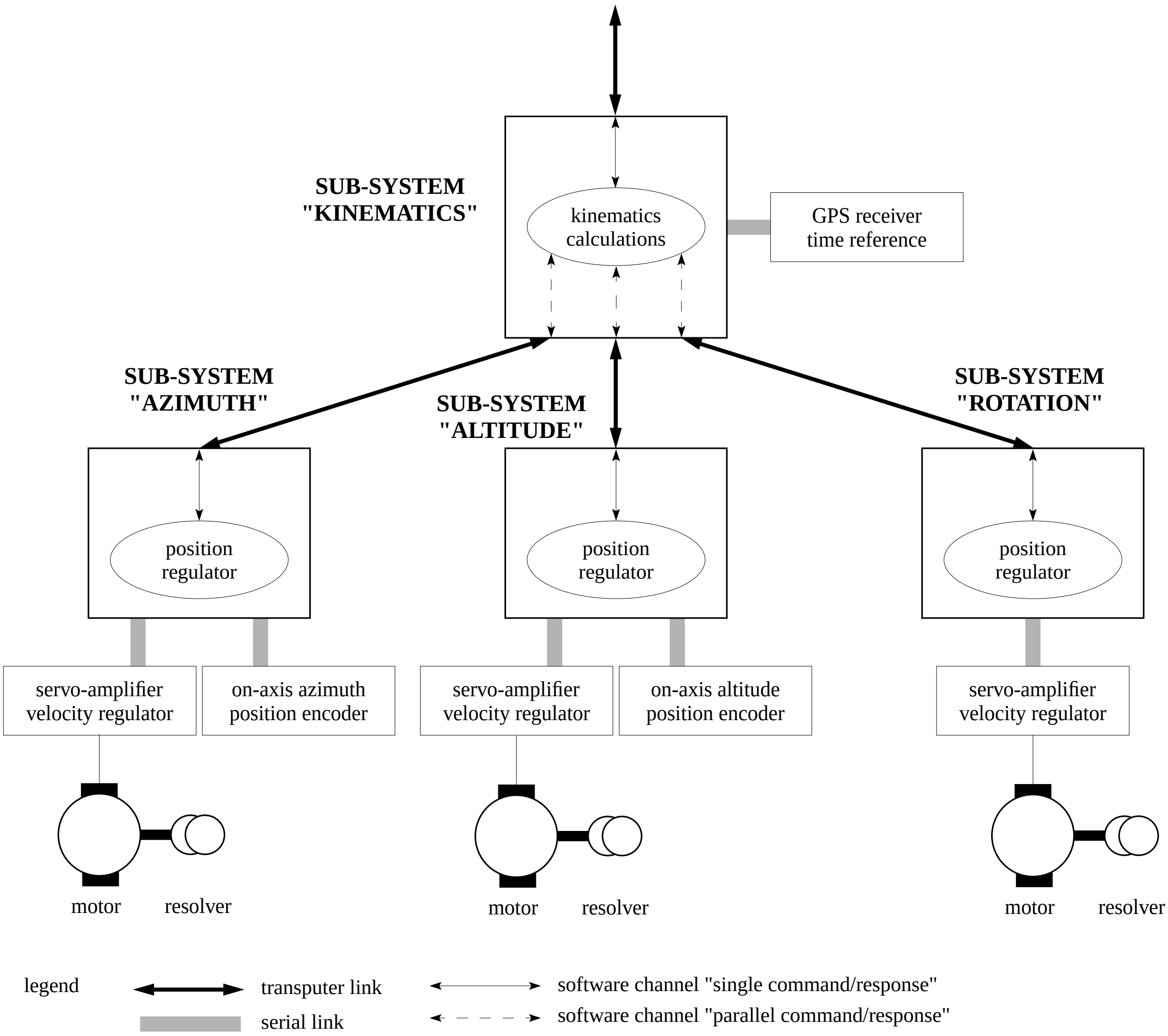



*Figure 4.1: Axes command structure*

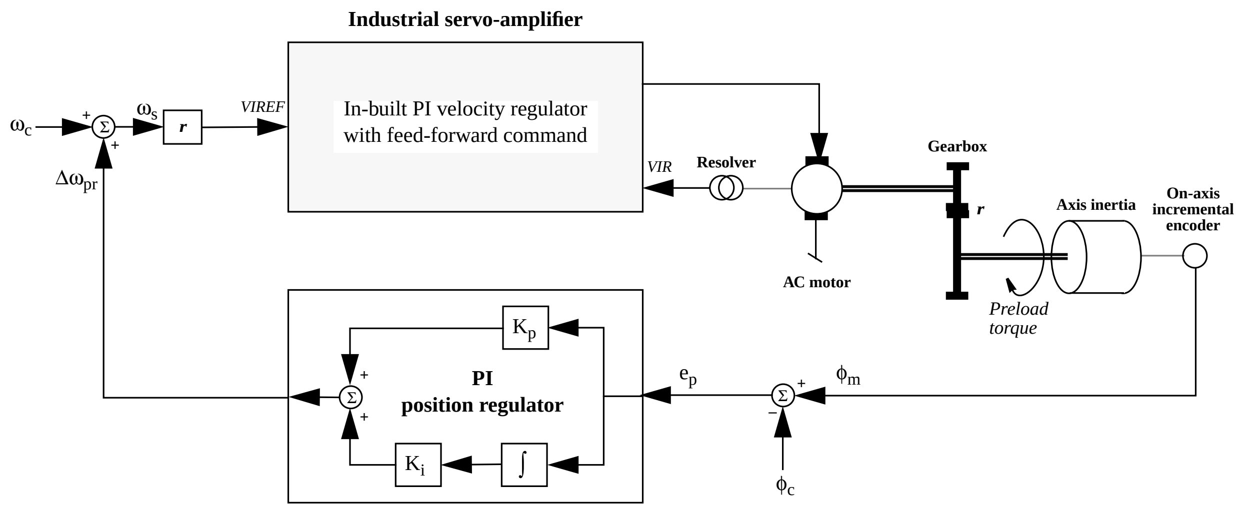
### 4.2 Servo-control of the axes

The servo control of the azimuth and elevation axes of the telescopes is composed of 2 regulation stages (Fig. 4.2):

1. The first stage is the velocity regulation achieved by the industrial servo-amplifier. Its sampling period is 0.3 milliseconds. The velocity regulator is a classical PI with a feed-forward command which integrates the inertia, frictions and preload torque parameters. The adoption of such standard solution has major impact in performances:

   - big linearity of the torque response thanks to the integrated current regulator which linearize the transfer function,
   - an efficient velocity control in the non-linear zones where the useful torques are near the friction torques,
   - short response-times without introducing stability problems thanks to the integrated feed-forward command;

2. The second stage is a PI regulator on the position error of the axis. The position measure is achieved by an on-axis encoder. The corrections are introduced at a sampling period of 20 milliseconds. The position errors corrections are achieved by a regulation task running in the processor of each axis sub-system (AZIMUTH and ALTITUDE).




| Legend | | | | |
|---|---|---|---|---|
| | $\phi_c$ | on-axis position setpoint of the celestial object | VIREF | motor velocity setpoint |
| | $\phi_m$ | axis instantaneous position | VIR | motor instantaneous velocity |
| | $\omega_c$ | on-axis velocity setpoint of the celestial object | | |
| | $\omega_s$ | effective axis velocity setpoint | r | drive reduction ratio |
| | $\Delta\omega_{pr}$ | position regulator contribution on the axis velocity | $K_p$ | position regulator proportionnal gain |
| | $e_p$ | axis instantaneous position error | $K_i$ | position regulator integral gain |

*Figure 4.2: General layout of the servo system for azimuth and elevation axis*

The axis servo control presented above is a classical control scheme implemented in several bigger telescopes. Based on industrial automation components, its successful implementation on our telescopes has permitted to reach linearity and dynamics performances well controlled in torque, velocity and position. It is also important that this was largely eased by an intrinsically very accurate and rigid mechanical structure.

### 4.3 The on-axis position coding

The sensor of the axes servo system is an incremental, exposed reflected light angle encoder mounted directly on each axis. This is unique for telescopes of such small size and this solution contributed mainly to the excellent positioning performances which had been obtained. This angular measurement system is an Heidenain LIDA system usually used for the machine-tool. It is composed of a measuring scale made of two steel tapes surrounding the perimeter of each axis (total length of 4,5 meter) and by scanning heads. The grating period is 100 µm, corresponding to a resolution angle of 28.8 arc seconds. Each sensing head signal is interpolated by a factor of 100. Then, the incremental counter board performs a X4 multiplication, giving a theoretical resolution of 0.07 arcsecond. The readout of the position counters is made in 0.4 ms for each axis. It is nevertheless well known that there is a significant difference between resolution and accuracy. A calibration of these measuring system has shown that their precision is limited to 0.3 arcsecond (peak-to-peak) on the axis because of a systematic noise introduced by the interpolation electronics. The azimuth axis has 4 heads arranged each 90˚. The elevation has 2 heads separated by an angle of 40˚.

### 4.4 The axis drives

The azimuth and elevation axes are driven by AC-servo brushless motors via a gearbox with a reduction of 1440. The motors have a nominal torque of 7 Nm limited mechanically to 1 Nm. The over-dimensionning of the motors permits to ensure a sufficient shaft stiffness. They are fed by applying a sinusoidal three-phase current to windings of their stator. An angular position transducer (in our case, a resolver) is used for the negative feedback of commutation of the phases and for the in-built velocity and position regulator of their respective servo-amplifier. This type of motor is particularly appropriate for the applications where dynamics is significant, such as the drive of a telescope, because of its very weak inertia. Moreover, they present a weak rotor heating, a significant characteristic for the precision drives.

On the azimuth axis a motor pair is used. They work in opposition. The first acts as driver, and the second gives a preload torque opposite to the moving direction, preventing mechanical backlash of the gearboxes pinions driving the axis cog-ring. The elevation axis is driven by an identical mechanical system, except that the second anti-backlash motor was no more necessary. The axis is balanced to give a constant anti-backlash torque by gravity. Table 4.1 below summarizes the characteristics of both drives.

| DESCRIPTION | AZIMUTH | | ELEVATION |
|---|---|---|---|
| | Northern hemisphere | Southern hemisphere | |
| Weight | 8’100 kg (including elevation axis) | | 4’400 kg |
| Inertia (max. value) | 16’000 kg · m$^2$ | | 15’000 kg · m$^2$ |
| Useful running range | {–295,3˚; 82˚} | {–81,9˚; 295,8˚} | {12˚; 89˚} |
| Position coding accuracy | 0.3 arc second | | |
| Drive velocity resolution | $2.5 \cdot 10^{-2}$ arc second/s | | $2.5 \cdot 10^{-3}$ arc second/s |
| Maximal tracking velocity | 0.21 ˚/s | | $3.6 \cdot 10^{-3}$ ˚/s |
| Maximal tracking acceleration | $5 \cdot 10^{-5}$ ˚/s$^2$ | | $1.3 \cdot 10^{-5}$ ˚/s$^2$ |
| Tracking zenith blind spot | 0,9 ˚ | | |
| Pointing velocity | 3 ˚/s | | |
| Pointing acceleration | 1.5 ˚/s$^2$ | | |

*Table 4.1: axes drives characteristics*

### 4.5 The servo-amplifiers

The major asset for using industrial servo-amplifiers in the axes command scheme is to have an intelligent peripheral simplifying the task of regulation considerably at the processor level. Indeed, the setpoints generation unit of the servo-amplifier, as its regulator with *a priori* command deal with the most time-expensive calculation tasks in the real time control being carried out in the local processor, i.e. the trajectory interpolation computations and the servo control. In addition, this off-the-shelf solution saved us the manpower and the development time of a similar regulator. The major drawback, fortunately not penalizing, is to parametrize the regulator according to a procedure given by the manufacturer, without however being able to make its synthesis, according to the traditional methods of control engineering (difficult modeling). The servo-amplifiers are commanded by the control system, a serial communication link at 19.2 kBauds. The command dialog for velocity updating takes 5 milliseconds.

## 5. CONCLUSION

The first telescope has been in use since May 98 achieving more than 100 pointings every night. Until now, no failure has been caused by hardware or software disfunction. This incredibly high reliability proofs the validity of the adopted concepts. The modular design of the control system permitted to develop comfortably each module according to their availability depending on the workshops workload. From a project management point of view, this flexibility of development is certainly a success factor in the achievement of such a huge project in a rather small institute such as the Geneva Observatory. The performances obtained in terms of tracking precision (0.3 arc second in 10 minutes time), pointing accuracy (3 arc seconds), operational reliability and automation degree, made the Geneva 1.2-m telescopes unique in their category. The second unit with its field rotator is currently in its final test phase in Geneva. It will be in function on its site at the end of 2000.

## 6. ACKNOWLEDGMENTS

The authors wish to thank all technical staff colleagues of the Geneva Observatory who have contributed in the realization of the telescopes and thus permitted the successful implementation of the here above presented concepts. In particular, thanks to the project engineers Charles Maire for interfacing the telescope control system with the observatory system, to Emile Ischi who supplied a relevant contribution for the integration of the various electromechanical devices into the control system and to Geert Davignon for his help in several calculation problems. Acknowledgments are also due to the astronomers who have contributed efficiently to improve the system reporting accurately the problems occurred in the earliest months of the telescope life.

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