Primary mirror control system for the GALILEO telescope

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Abstract

The Italian GALILEO telescope (TNG) is in an advanced phase of construction. Among the various new technical aspects of this telescope the active optics system is now receiving special consideration.

In particular, the optical and informatic groups are considering the definition of the control environment dedicated to the active-optics.

A solution based on an array of interconnected 16bit transputers is here described with the main requirements for the inter-communication and monitoring software.

1 Introduction

The new generation of actively controlled telescopes (NTT, JLNT, VLT) is based on a complex control scheme allowing support and positioning of mirrors.

In the M1 case each mirror support system must be driven to a required force and monitored for the effective delivered force on the mirror contact point. Driving such an array of actuators (78 contact points) using a distributed system of local microcontrollers can allow some advantages here described.

Local control assures quick positioning loop, with the highest allowed bandwidth (limited only by the mechanical constraints).

The array can be configured in order to obtain direct estimation of the forces to be applied.

Modern microprocessors have built-in hardware and firmware wich largely eliminate the effort needed to provide safe and fast intercommunication mechanisms.

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Due to the amount of interaction needed between optical and mechanical components it is attractive to extend the microcontroller array to cover all active parts like M2, M3, tracking cameras, wavefront analizers and concerned optics.

2 The TNG M1 cell

The mechanical layout of the TNG M1 cell is the same used for the ESO-NTT telescope, from wich all the concepts concerning the active optics[1] are fully retained.

In particular to M1 is demanded the elastic correction of the Zernike terms of third and higher order, with the only exception of third order coma term, which is corrected using modelled movements of the M2. Focus term is also corrected by M2.

The only different concept of TNG from NTT is the use of M3 for the correction of tilt terms. This kind of correction is obtained in NTT in the usual way moving the whole telescope (tracking).

Following prescriptions given by ESO[2] the cell consists of a set of 75 active supports based on astatic levers; they are driven in order to elastically compensate wavefront deformations detected by a wavefront sensor in a closed loop.

Three additional fixed supports spaced 120^o apart from each other are used to monitor the overall exchange of forces between astatic levers and mirror.

In addition a number of passive radial actuators, at the outer border and in the central hole, provide the optimal radial support; the central hole support will be equipped with load-cells in order to monitor the radial exchange of forces.

Modal elastic deformation of the primary is obtained through variation of the overall pattern of forces applied by the supports.

Such task is obtained in two ways:

1. Acting on a pre-load spring, *i.e.* setting the offset term, as usual in a non-active telescope;
2. Acting on a counter-weight lever arm driven via a motor.

The monitoring of the net force developed by each single actuator can be obtained from a load-cell interposed directly between the mirror contact point and the actuator lever system. Positioning of counter-weight is directly made by the motor at a speed monitored with a tachometer.

3 Control scheme for TNG optics

The overall correction of the optical figure (including tilt term, *i.e.* tracking) is performed on the three mirrors using a number of closed control loops as reported in Fig.1.

Each loop is composed by a circuit wich sets the actuator speed and a circuit wich reacts to the information error, *i.e.*:

- velocity loop: the inner loop closed between motor and on-axis tachometer;
- position loop: the outer loop where position (or force) is sensed and held.

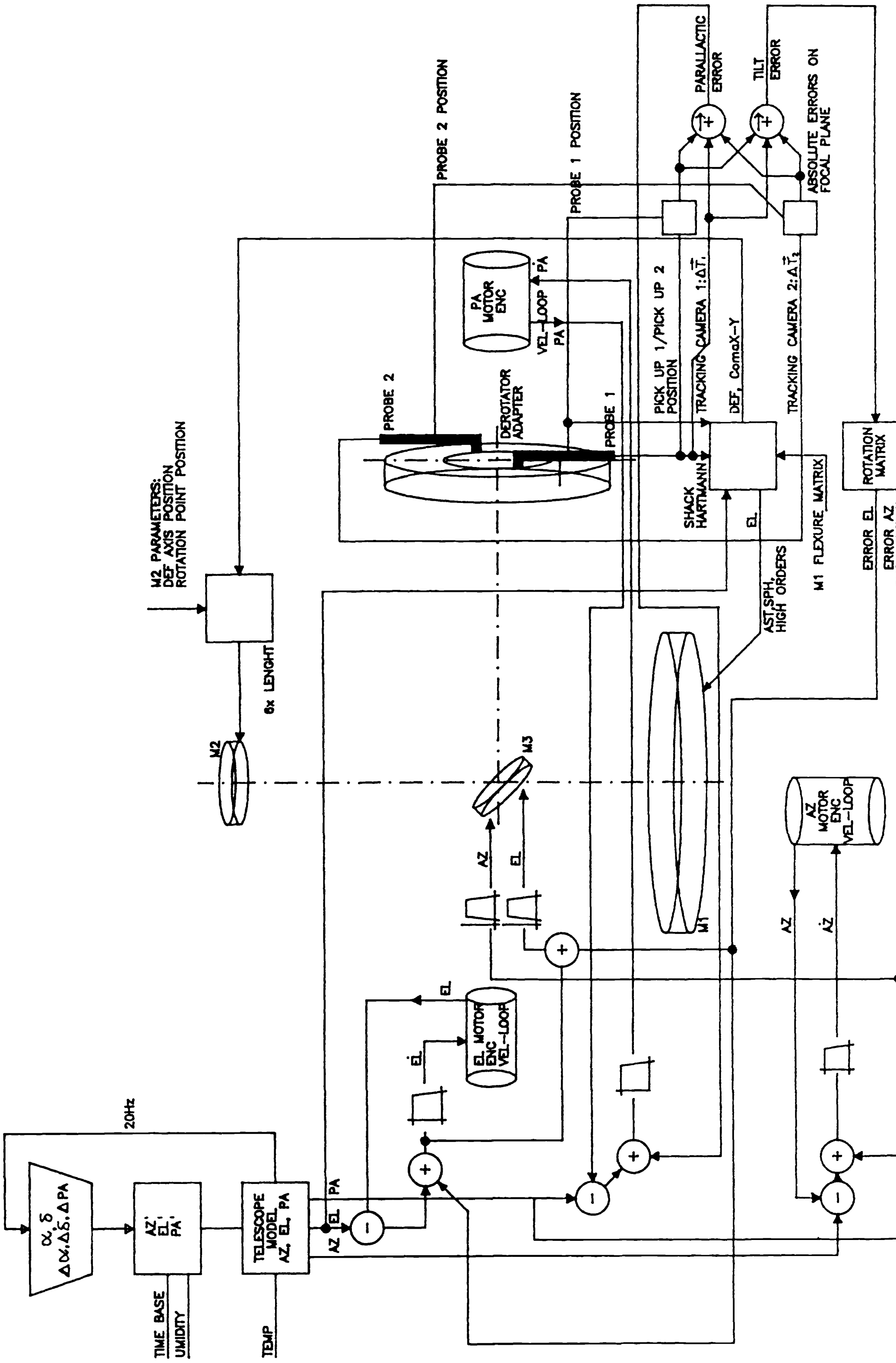

Figure 1: The overall layout of the control-loops for the TNG.

Error information can be obtained from direct sensing (*i.e.* encoders, LVDT, etc.) or from more complex operations via Shack Hartmann (SH) analysis.

Although control loops are all identical from the point of view of basic functions performed, it should be noted that there can be a partition in the time domain based on the different actuator and sensing rate used. A peculiar case is M3 mirror where the error signal is obtained from tracking cameras and correction is obtained at a higher rate than that used for M1 and M2.

As usual for active telescopes the first step of optical correction is based on the analysis of the wavefront produced by the telescope itself. This information is all that is needed for the outer loop in Fig.1. The source of error information can be a SH sensor looking at the focal plane, a traking camera looking at a star on the focal plane or a combination of both.

It should be noted that in the case of M2/M3 the position is sensed, while in the case of M1 the applied force is directly detected (M2/M3 are positioned while M1 is elastically deformed).

As a consequence stimuli to each mirror system are subdivided as follows:

- M1 - 75 forces;
- M2 - tilt around local curvature centre on its vertex (two angles, decentering coma);
- M2 - distance from M1 along optical axis (focus);
- M3 - tilt around two horthogonal axes (two angles, focal plane tilt).

Traditionally the tilt term is corrected during the tracking by the telescope driving system at a frequency limited by the overall telescope structure (0.2 Hz for the TNG) although the information available about tilt error can cover a wide frequency bandwith.

The error information to drive mirrors is obtained from different sources:

- The tracking model plus the telescope model - (20 Hz);
- The main axes encoders - (about 500 Hz);
- The SH analizer - (seldom used for M1 correction, 0.3 Hz for focus correction on M2 if reference star is available);
- The tracking cameras - (up to 50 Hz if reference stars are available).

Errors introduced during tracking can be of different kind:

- flexures of the M2 support system while changing elevation angle - coma plus tilt at low rate;
- wind-buffeting - tilt at frequencies around 1 Hz;
- temperature changes during the nigth - focus changes at low rate;
- tracking errors and instabilities - movements of focal plane at a rate of some Hz;
- low frequency seeing induced effects on tilt term.

The above list of error sources can be better visualized on the diagram in Fig.2; here one can see the frequency covering of each Zernike term concerned with different sources of error during tracking.

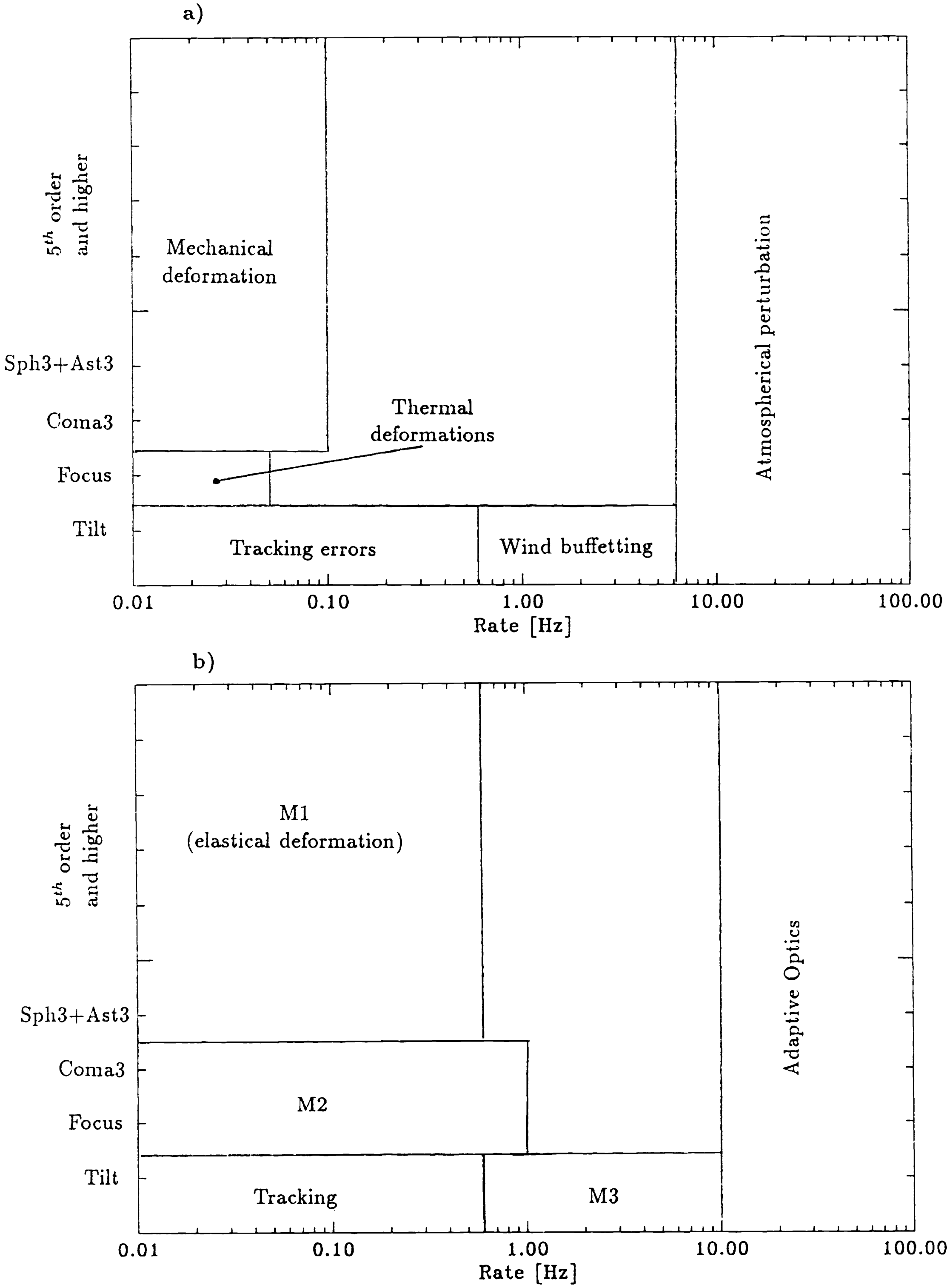

Figure 2: **a)**: Sources and **b)**: correction capabilities concerning the imaging properties of an active-controlled telescope.

4 Data handling

Due to the huge number of actuator systems to be monitored and controlled, a large amount of information of different kind must be handled in a proper way. Information can be, roughly, subdivided in:

1. commands (operators plus operands);
2. telemetry (parameter plus status).

For the M1 case only the telemetry has to take into account:

- load cells (78 axial plus 4 radial) - 82 voltages;
- motor tachometer - 75 voltages;
- mirror cell environment (temperature, humidity);

while there are 75 motor speeds to be commanded, *i.e.* 75 voltages to be set.

Commands are of course more complicated than the simple setting of the speed of a single motor; in fact one wishes to handle all motors at the same time in order to avoid mirror support losses of balance or to continuosly control the force on all supports.

In such way it is allowed to close the loop between load cells and motors during tracking.

This implies the need of a dedicated microcontroller for each support (node) and the possibility of quick communication with and among nodes.

5 The transputer network

There is a number of recent technological developments concerned with astronomy based on transputer arrays. For istance on the field of detector controllers[3] and on the field of telescope and instrumentation control[4].

There are two common advantages pointed out in such a choice:

1. the possibility to have concurrent processing at the level of a single node and to spread on multiple nodes;
2. the possibility to have a mechanism of fast intercommunication based on four interconnectable serial links per node.

It is to be noted that the above two mechanisms are completely embedded inside the hardware achitecture of the transputer chip and are under the direct control of the transputer development language (OCCAM). This means that the amount of external hardware for a complex array of nodes is minimum (even no hardware at all for short distances, about 30 cm) and there is no need of software drivers and special handling of concurrent communications.

An application example of transputers as local microcontrollers for M1 support array is given in Fig.3.

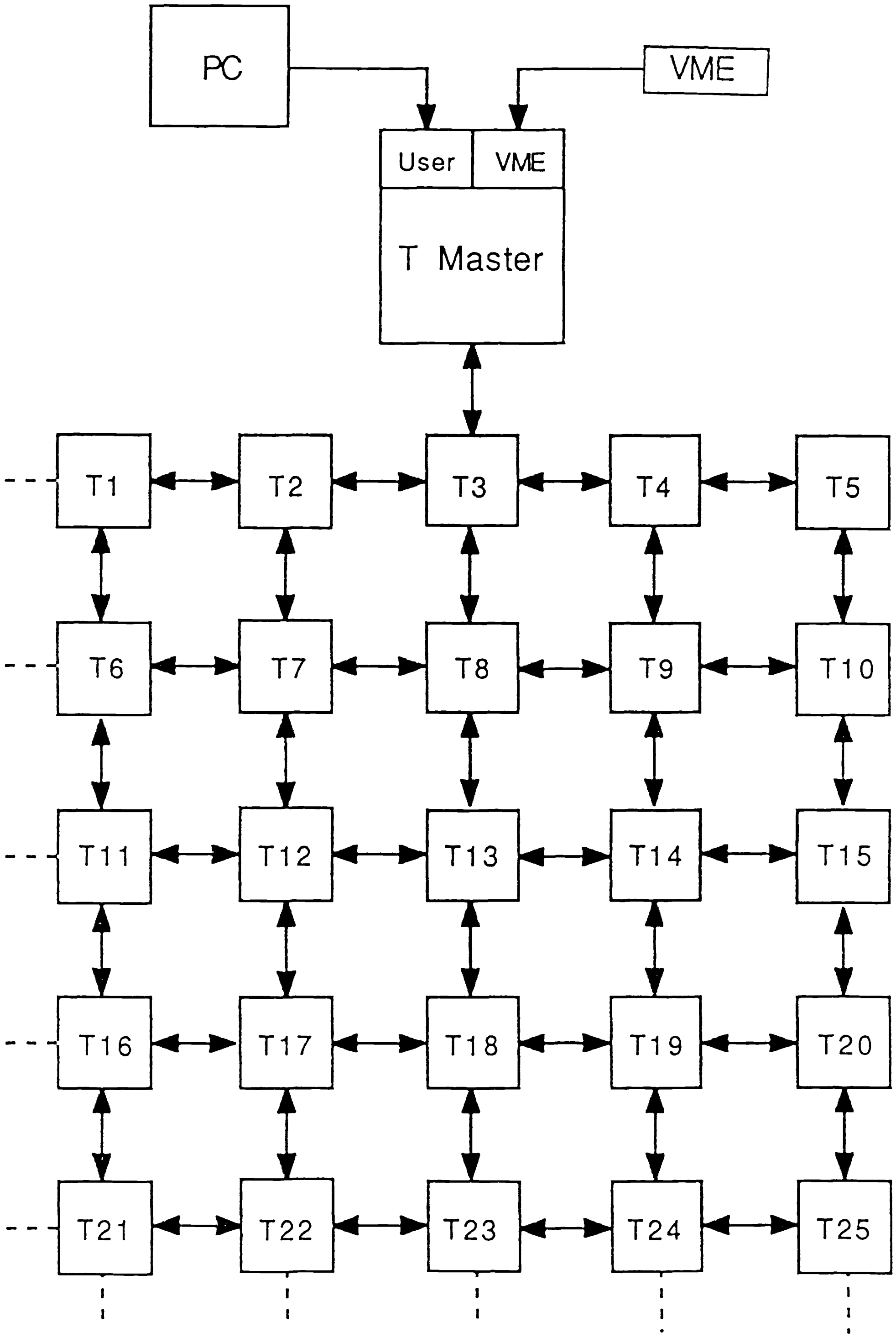

Figure 3: A possible interconnetion layout for M1 transputer system.

One can see the presence of a master transputer board which handles the overall array of nodes. This board is a commercial part and can be obtained as a PC compatible card or as a VME crate compatible card. A 32 bit T800 transputer with built-in floating-point co-processor is available on this board.

The former solution (PC) is preferred for software development and debugging while the second (VME) is better suited for integration on the overall telescope control system, based on VME crates.

The master link, *i.e.* the connection shown in Fig.3 between the master and the node array, can easily be supported by optical fibres, providing insulation between the informatic and the M1 environments.

Interconnection between single nodes can be designed in a number of ways, provided all nodes are connected with at least one link to a *neighborhood* node. Typically used configurations can be matrix-like (Fig.3), tree structure or pipe-line arrangement.

The choice depends on various factors like maximum link length, redundancy on connections, needed communication speed between master and single nodes and between nodes; the choice we made is to let the constructor free to assemble the simplest network following hardware constraints and to provide a network message protocol (routing protocol) which ensures the possibility to identify and communicate with each node.

Node identification is performed automatically at boot-up by each node reading a 8 bit dip-switch mounted on the node board. Routing of commands and telemetry is obtained placing on each message an header with the routing-path (*i.e.* a stream of node identificators which maps the required path from the message sender to the message receiver). The advantage of this communication system is the possibility to handle every kind of transputer network modelled for a specific control application.

6 The motor-controller board

Fig.4 shows what is inside a single actuator node.

The transputer is a T425 16bit chip with 4 serial links working at the maximum speed of 20 Mbit/sec. On a single-size board there are the following built-in functions:

- 4 analog to digital 12 bit channels;
- 4 digital to analog 8 bit channels;
- a read-only preselectable 8 bit dip-switch;
- two 8 bits input-output ports.

The load-cell is connected to one A/D input through a signal conditioner (Analog Dev. 1B31) which provides also the bias voltage. The resolution achieved is of the order of 30 grams with a Philips PR6206/22M1 cell.

The motor speed loop is obtained via an op. amp. based circuit, so, in the M1 application, the transputer is concerned only with the handling of the required support force (*position* loop). Fig.5 shows the organization of the code mounted on the T425 at start-up.

Each box is a concurrent task running on the processor; tasks can be divided in different layers:

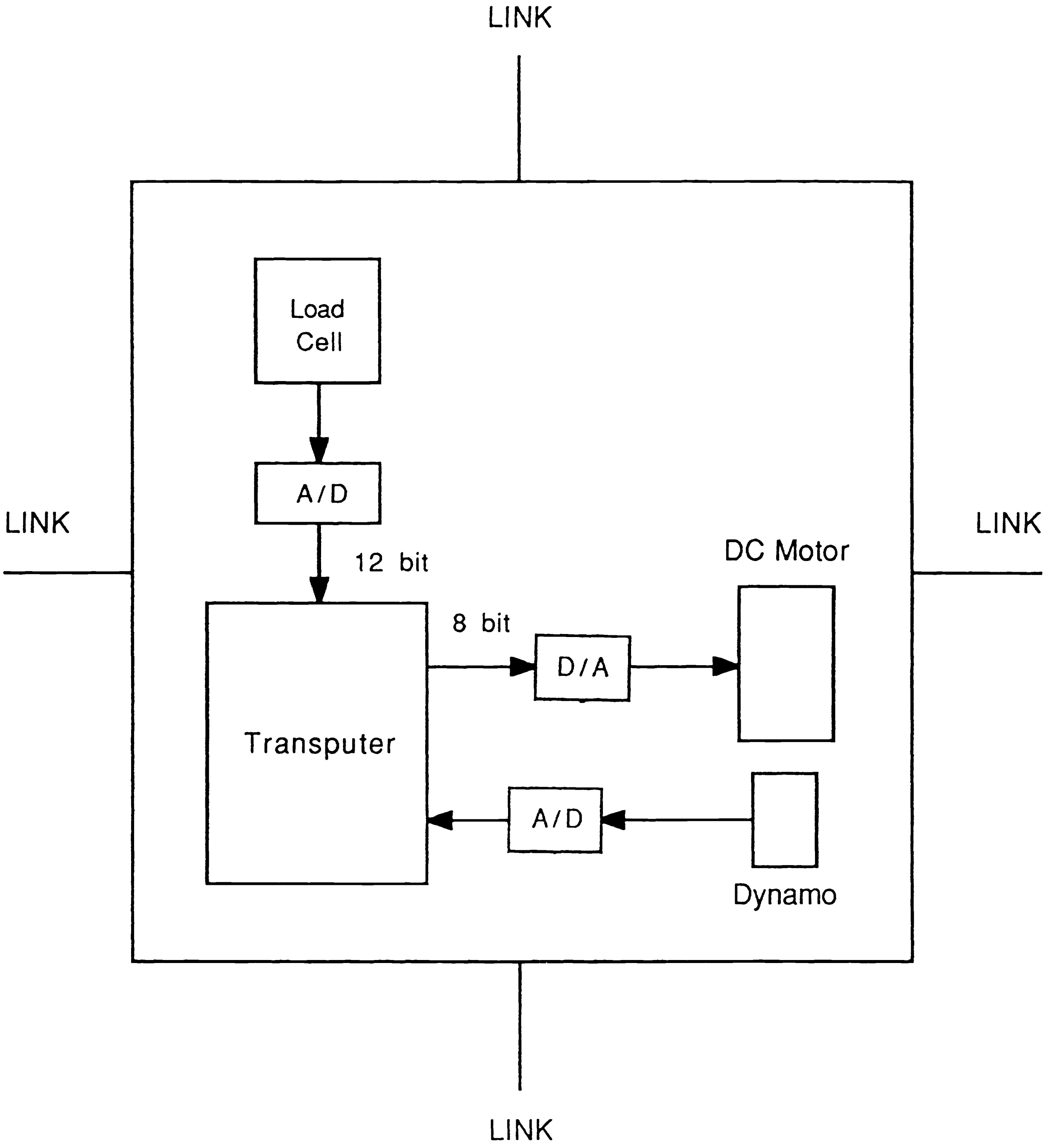

Figure 4: Hardware structure on a single actuator node.

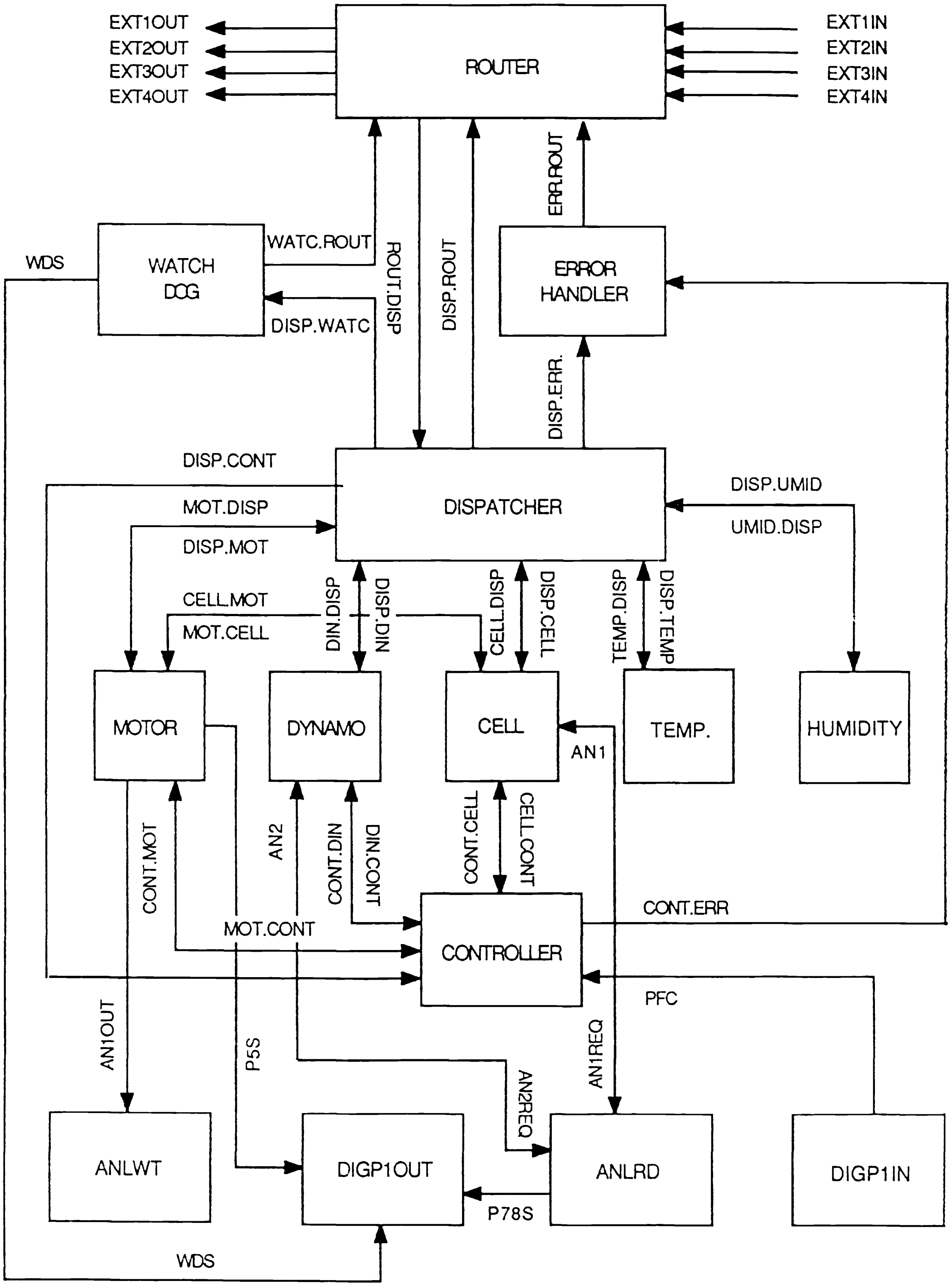

Figure 5: Software structure on a M1 node.

- Routing layer: this task is dedicated to the handling of links, *i.e.* to receive/send a message from/to a node and to switch a message to the next node.
- Dispatcher layer: this task sends commands to the application tasks, holds a local data-base and generates telemetry.
- Application layer: this is the group of tasks dedicated to the specific application.

In Fig.5 one can see, among others, the motor, tachometer and cell software drivers. It is up to this layer to transform quantities from engineering to physic dimensions (like A/D units to grams and viceversa).

7 Conclusions

A prototype of board based on a 16bit transputer processor has been developed and checked. The board can be configured, with minor modifications, as a controller for several kinds of actuator systems based on closed loop feedback. This board can be part (node) of a network of similar devices matching a particular control operation; this possibility is assured by four serial links extendable to medium distance through optical fibres. The handling of every kind of configuration is assured by a software routing protocol mounted on the master node and down-loaded at start-up.

Acknowledgments

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