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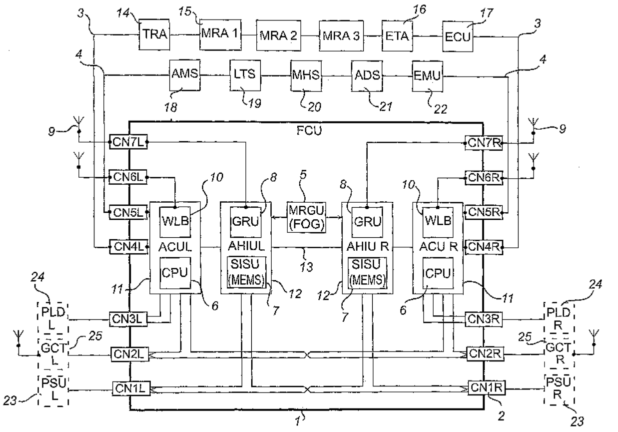

(57) Abstract: A control system for unmanned vehicles, such as unmanned aerial vehicles, which system comprises a central control unit (1) which comprises the components which are the most critical for the control of the vehicle. The central control unit (1) comprises at least one high performance attitude measuring sensor system (5), at least two low performance attitude measuring sensor systems (7), at least two position measuring sensor systems (8) and at least two calculation units (11) which are arranged to calculate the attitude and the position of the vehicle. The units function independently of each other, but are capable of communicating with each other via an internal bus (13). The system further comprises a plurality of actuating means (14, 15, 16, 17) and/or sensors (18, 19, 20, 21, 22) which are distributed externally of the central control unit (1). The distributed means (14, 15, 16, 17) and/or the sensors (18, 19, 20, 21, 22) communicate with each other and with the central control unit (1) via at least one bidirectional ring bus (3, 4), to which the means and/or the sensors are connected in series and which ring bus (3, 4) is connected to the central control unit (1) by at least two ports (2).

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CONTROL SYSTEM

Technical Field

The present invention relates to a control system for unmanned vehicles, such as unmanned aerial vehicles, which system comprises a central control unit.

Technical Background

Unmanned aerial vehicles or UAV systems, with the ability to fly without requiring continuous intervention by a human operator, have until now been intended exclusively for military markets. Recent years, however, have seen an increasing demand from a broader and more varying market, while simultaneously the military requirements have been raised. Concurrently with this development, the requirements for the reliability of the systems and their capacity to make independent decisions in critical situations to avoid damage to property and personal injury have increased dramatically. This means in particular that the requirements on the control systems have increased.

A common problem of many UAV systems, and also of unmanned land and sea vehicles/craft is that they are relatively small and light compared to manned vehicles. While the low weight and the small size are one of the many advantages of a UAV system compared to conventional manned vehicles, this also means that the lifting capacity and the available space are very limited. The limited space is particularly an issue in hovering UAV systems, that is rotor-equipped vehicles. This results in problems which are unique to UAV systems and which often make it impossible to apply to UAV systems the technology used to construct safe and reliable control systems for manned aerial vehicles.

In addition to the requirements on low weight and volume, there is also a demand for reasonable costs as UAV systems are expected to be a great success when the civilian applications start to abound.

In manned aerial vehicles, safety and reliability are traditionally provided by simply doubling or tripling all the components included in the control system. This is called two-channel or three-channel control systems.

This means that all the sensors, calculating units, actuating means (actuators) and communication paths between them are doubled or tripled.

Owing to the complexity, weight and volume of such control systems, these solutions are often excluded in many small and medium-size UAV systems (with a take-off weight of 50 to 200 kg). In addition to these requirements, there is also a demand for reasonable costs of the systems. The big challenge in designing UAV systems is thus to find the optimal compromise between safety, on the one hand, and complexity/weight/volume/price, on the other hand.

US 2006/0058928A1 discloses a system and a method for controlling unmanned vehicles. This document describes a control system of the vehicle, consisting of one central processor which is in electronic communication with a plurality of sensors distributed in the vehicle. This system is, however, vulnerable in at least two ways: a failing communication channel between the processor and a sensor risks to negatively affect controllability, and the failure of the central control unit or an individual sensor negatively affects controllability.

EP0754991 discloses a control system for a manned vehicle, in which a central control unit is eliminated and in which the control function is completely distributed among a plurality of distributed intelligent control units, which are capable of communicating with each other by groups via an optical ring bus. Such a system is, however, unsuitable for use in an unmanned vehicle since the components included in the form of, among other things, intelligent control units and high performance optical communication paths with associated interfaces result in a complex, expensive and heavy solution.

Summary of the Invention

Therefore an object of the present invention is to provide a control system, which is designed such that the above-mentioned problems are eliminated or considerably reduced.

This object is achieved according to the invention by a control system which is of the type defined in the preamble to claim 1 and characterised in that the central control unit comprises the components which are the most critical for the control of the vehicle, that the system further comprises a plurality of actuating means and/or sensors which are distributed externally of the central control unit, and that the distributed means and/or sensors communicate with each other and with the central control unit via at least one bidirectional ring bus, to which the means and/or the sensors are connected in series. The ring bus is connected to the central control unit by at least two ports.

The solution with at least one bidirectional ring bus provides improved safety and reduced risk of, for example, a cable failure affecting the control of the vehicle.

As the system is designed according to a distribution principle, that is a plurality of individual components communicating with each other via one or more digital buses, a high degree of flexibility is achieved as well as an even distribution of the mass over the extension of the vehicle. To achieve an optimal comprise between weight, volume, price and reliability (goal achievement), it is important to design the individual nodes/components of the system with great care.

Since the components which are the most critical for the control of the vehicle, such as the calculation units and the attitude and position measuring sensor systems, are gathered in the central control unit, there is an even smaller risk of operational disturbances caused by failure in cabling and connectors (bad contact in the most critical functions).

Moreover a solution, in which the central unit is alone responsible for the control of the communication with the distributed units, presents the advantage that the distributed units, which of course are more than one, are cheap, uncomplicated and cost-efficient to produce. The relatively simple nature of the distributed units also offers the advantage that the demands on the capacity of the communication paths, interfaces and connectors can be low, which further improves the cost effectiveness, weight and volume.

The present solution has the advantage that particularly critical sensors and calculation units can be doubled or multiplied.

The solution also offers the advantage that the distributed function units have a much simpler design and are considerably less demanding for the bus.

According to an embodiment of the invention, the distributed means and/or the sensors communicate with each other and with the central control unit via two mutually independent bidirectional ring buses, which are connected to the central control unit by four ports.

The fact that the bus is circular and not, for instance, star-shaped is an important aspect for many reasons as it contributes to a minimum increase in weight and volume, in spite of the double number of cables, and to a doubling of the number of signal paths. In, for example, a star-shaped network, the total cable length is much longer and there are either more connectors in the control unit or more external cross-connection units (that is increased complexity, weight and volume). The ring-shaped buses permit the bus traffic to flow clockwise or anticlockwise or in both directions simultaneously depending on if there is a cable failure in the bus. This is also the case of the power supply which can be distributed by the same bus cabling.

In another embodiment of the invention, the central control unit comprises at least one high performance attitude measuring sensor system and at least two low performance attitude measuring sensor systems.

By this design of the central unit, at least one high performance attitude measuring sensor system is combined with two or more low performance sensor systems to maximise reliability. To allow safe error detection of a sensor, a minimum of three independent units are needed for the "majority" principle to be applicable, that is if one of the sensors deviates significantly from the other two this sensor is considered as defective. The high performance system is, for example, based on fibre-optic technique (FOG) or on the principle of laser interference, so-called laser gyro. These sensors are expensive (or even very expensive) and have a volume which for physical reasons is not insignificant. Owing to this, only one such sensor system is included in the control system. The low performance sensors are based on so-called microelectromechanical technique (MEMS) and have a small volume, low price and moderate performance. They can thus advantageously be duplicated at low cost.

In yet another embodiment of the invention, the central control unit is designed such that the high performance attitude measuring sensor system is located in the centre of the central control unit and the at least two low performance attitude measuring sensor systems are located on opposite sides of the high performance attitude measuring sensor system.

This results in an advantageous weight distribution in the vehicle as a high performance sensor system is heavier than a low performance sensor system. This disposition also results in the high performance system being located as close as possible to the centre of mass of the vehicle, which contributes to improved measurement accuracy.

According to another embodiment of the invention, the central control unit comprises at least one interface unit, which comprises at least one low performance sensor system and at least one position measuring sensor system and through which interface unit all power supply to all the distributed means and/or the sensors passes to allow measuring of the power consumption.

The interface unit is also capable of disconnecting the power supply to the functions of the system that are not safety-critical, such as a payload.

Owing to this, an early detection of errors about to occur can be provided by measuring irregular deviations in the power consumption, which in turn makes it possible to take a decision to quickly land the vehicle due to risk of voltage failure.

According to another embodiment of the invention, the central control unit comprises at least one high performance attitude measuring sensor system, at least two low performance attitude measuring sensor systems, at least two position measuring sensor systems, and at least two calculation units arranged to calculate the attitude and the position of the vehicle. These units function independently of each other, but are capable of communicating with each other via an internal bus.

In this way, the central control unit is composed of two essentially identical halves. By the internal bus, the two calculations units have access to data from all the available sensor units, which means that the evaluation of all sensor data can be carried out by both calculations units independently of each other. This is possible even if one of the calculation units fails, since the bus and the interface units are designed to function irrespective of the accessibility of the calculation units.

The principle is that one of the two calculation units acts as a master (primary unit) in the buses under normal circumstances. This master independently decides on the bus traffic. The other calculation unit acts as a passive node monitoring all traffic, and has the capacity, on the one hand, to retrieve data from all the distributed sensor and, on the other hand, to determine if the other calculation unit has failed or if a cable failure has occurred. When such an event has been established, the passive calculation unit can decide to act as a master for the bus in question.

Brief Description of the Drawings

In the following, the invention will be described in more detail with reference to the accompanying drawing.

Fig. 1 is a block diagram illustrating the basic structure of the invention.

Description of a Preferred Embodiment

The Figure shows a control system according to the invention. The control system comprises a central control unit 1. The central control unit 1 comprises a high performance attitude measuring sensor system 5, which is located in the centre of the central control unit. The high performance sensors 5 can, for example, be based on fibre-optic technique (FOG) or the principle of laser interference, so-called laser gyroscope, or a similar technique. These sensors are expensive and have a volume, which for physical reasons, is not insignificant.

The central control unit 1 further comprises two low performance attitude measuring sensor systems 7, which are located on opposite sides of the high performance sensor system 5. The low performance sensors 7 can, for example, be based on so-called microelectromechanical technique

(MEMS) or a similar technique, resulting in a small volume, low price and moderate performance.

By combining a high performance attitude measuring sensor system 5 with two low performance sensor systems 7, three independent units are obtained, providing maximum reliability and safe error detection of a sensor since at least three independent units are needed to be able to apply the "majority" principle, that is if one of the sensors deviates significantly from the other two this sensor is considered as defective.

By a high performance sensor system 5 being heavier than a low performance sensor system 7 and by arranging the heavier high performance sensor system 5 in the centre of the central control unit 1 and the two lighter low performance sensor systems 7 on opposite sides of the high performance sensor system 5, an advantageous distribution of the weight is obtained in the vehicle. By this disposition, the high performance system is also located as close as possible to the centre of mass of the vehicle, which contributes to improved measurement accuracy.

By "attitude" is meant the solid angles and the roll, pitch and azimuth angles of the vehicle.

The unit 1 also comprises two position measuring sensor systems 8, which are also located on opposite sides of the high performance sensor system 5.

By "position" is meant the location of the vehicle in space as expressed, for example, in latitude, longitude and sea-level altitude.

By "attitude and position control" is meant control actions required to keep the vehicle straight and in correct position, that is the correct roll, pitch and azimuth angles and the right position in space, irrespective of outer "disturbances" in the form of wind, turbulence and thermals (or heavy sea, wind, irregularities in the ground, slipperiness and the like in the case of sea and land vehicles).

The position measuring sensor systems maximise the reliability of the control system and serve to measure the azimuth angle of the vehicle with great accuracy. The azimuth angle is calculated by arranging at least two aerials 9 at a distance from each other, for example under the main rotor disc and at the rear end of the tail boom of a helicopter, and by using simple trigonometry. This results in high angle accuracy and significantly better tolerance to disturbances (in particular interfering magnetic fields) compared to conventional magnetic compasses thanks to the technical development of the sensors.

A low performance sensor system 7 and a position measuring sensor system 8 together form an interface unit 12.

The central control unit 1 also includes two calculation units 11, each comprising a processor (CPU) 6. According to an embodiment of the invention, the calculation unit also comprises a short distance radio link 10. The link 10 is not necessary for the function of the calculation unit, but it can increase safety during the actual flight as it can continuously transmit information to the “ground”.

Also the two calculation units 11 are located on opposite sides of the high performance sensor system 5.

The most critical components of the control system according to the invention are the calculation units 11 and the sensors for measuring the roll, pitch and azimuth angles and the position and speed of the vehicle. To avoid the risk of operational disturbances caused by errors in cabling and connectors, etc, it is essential for these sensor elements 5, 7, 8 to be contained in the central control unit 1.

The central control unit 1 comprises the components which are the most critical for the control of the vehicle and thus has a high performance sensor system 5 which is centrally placed and two parts (halves) which contain the corresponding components. The parts function independently of each other, but can also communicate with each other via a bus 13, preferably an internal high-speed bus.

By the internal bus 13, both calculation units 11 have access to data from all available sensor systems 5, 7 and 8. Consequently, the evaluation of all sensor data can be performed by both calculation units 11 independently of each other and irrespective of whether one of the two units ceases to function. This is possible even if one of the calculation units fails since the bus

13 and the interface units 12 are designed to function independently of the accessibility of the calculation units 11.

In addition to the central control unit 1 and its included parts, the control system also comprises a plurality of distributed actuating means 14-17 and sensors 18-22, which communicate with the central control unit 1 via two mutually independent circular buses 3 and 4.

These units are distributed so as to be located in different places for physical reasons (for example a magnet sensor must be located at a long distance from interference sources, and actuators have to be located close to the control surfaces/ rudders) and for optimising the distribution of the weight in the vehicle.

The actuating means 14-17 communicate via an actuator bus 3 and the sensors via a sensor bus 4. The means 14-17 are connected in series to the actuator bus 3. The sensors 18-22 are connected in series to the sensor bus 4. The actuator bus 3 is connected to the central control unit 1 by two ports 2. The sensor bus 3 is connected to the central control unit 1 by two ports 2. As the buses 3 and 4 are ring buses, they have two ends each and are connected to the control unit 1 by two ports 2 located on opposite sides of the control unit 1.

The fact that the buses 3 and 4 are circular and not, for example, star-shaped is an important aspect as it contributes to a minimum increase in weight and volume, in spite of the double number of cables, and to a doubling of the number of signal paths. For example, in a star-shaped network the total cable length is much longer and there are either more connectors in the control unit or more external cross-connection units (that is increased complexity, weight and volume). The ring-shaped buses 3 and 4 are bidirectional, which makes it possible for the bus traffic to flow in the clockwise or anticlockwise direction or in both directions simultaneously depending on if there is a cable failure in the bus. This is also the case of the power supply which is distributed by the same bus cabling. Owing to the ring shape, it is also possible to determine exactly and unambiguously where a particular cable failure has occurred. In corresponding manner, two independent paths are obtained for the power supply if it is distributed by the same bus cabling.

As examples of distributed actuating means, mention can be made of: tail rotor actuator 14, main rotor actuator 15, engine control actuator 16 and engine control unit 17.

The actuator bus 3 is also bidirectional, which means that valuable status information can be retrieved from the actuators 14-17 and analysed by the calculation units. This is very important to allow early detection of errors about to occur in the actuators (for example increased temperature, increased power consumption/increased mechanical load, resulting setting angle, etc.).

As examples of distributed sensors, mention can be made of: fuselage monitoring sensor/vibration monitor 18, landing sensor 19, magnetic compass sensor 20, air data sensor 21 and engine monitoring unit 22.

The position measuring sensor systems 8 are, for example, supplemented by the external distributed magnetic compass sensor 20, which is disposed as far away as possible from all interference sources (for example on the outer end of the tail boom of a helicopter). This sensor 20 intervenes if the position measuring sensor systems 8 fail completely or partially. The sensor 20 can also be used to detect errors in the position measuring systems 8.

The principle of the central control unit 1 is that one of the two calculation units 11 acts as a master in the communication buses 3 and/or 4 under normal circumstances. This master independently decides on the bus traffic. The other calculation unit 11 acts as a passive node monitoring all traffic, but it also has the capacity to retrieve data from all the distributed sensors 18-22 and the actuators 14-17 and to determine if the other calculation unit 11 is failing or if a cable failure has occurred. When such an event has been established, the passive calculation unit 11 can decide to act as a master for the bus 3 and/or 4 in question. By monitoring which nodes in the bus are responding, it is possible to exactly localise a cable failure or a similar reason for a signal disturbance.

All power supply to all the distributed nodes passes through the interface units 12 to allow measurement of the power consumption. This is also an important aspect of early detection of errors which are about to occur.

Besides the central control unit 1, buses 3 and 4, aerials 9, distributed actuators 14-17 and sensors 18-22, the control system further comprises an additional number of distributed units, namely power supply units 23, payloads 24 and ground communication units 25.

The interface units 12 are capable of detecting deviations in the power supply 23, which in turn allows a decision to be taken to quickly land the vehicle due to the risk of an approaching voltage failure. In this situation, the interface units 12 can also disconnect the power supply to the functions which are not safety-critical, such as a payload 24.

The ground communication units 25 are connected via the central control unit 1 to both calculation units 11 to ensure reliable ground communication even if one of the two radio links is failing.

All the mechanical actuators 14, 15 intended for the actuation of the control surfaces are provided with double sensors for position measuring, as these sensors have been found to be particularly sensitive to environmental influence. It is, however, seldom possible to double the number of engines in these actuators due to the strict limitations on weight and volume.

Short distance radio links 10 according to some suitable standard (for example wireless LAN/WLAN, i.e. IEEE 802.11) are used to rationalise the communication with the central control unit 1 during development, testing and transmission of telemetric data. This is because disc space in the calculation units 11 and sensor data in real time are made available owing to the wide bandwidth offered by these radio links. The disc space in the calculation units 11 is also used to store data in a non-volatile manner to be able to later analyse the behaviour of the vehicle and to gather information about any possible problems occurring.

By a control system according to the invention, the inherent properties of small and medium size UAV systems are used, among other things, the fact that the vehicles are relatively small and that the cable paths are comparatively short (in relation to manned systems). Moreover, the technical development (for example miniaturisation, price reduction) of certain components is used so that the selected actions result in relatively small costs in terms of volume and price.

The most expensive components in a UAV control system are the attitude and position measuring sensors 5, 7 and 8. On the other hand, the technical development has resulted in low performance sensors of this type, which are much cheaper. The technical development has also led to a considerable miniaturisation of these low performance sensors and the calculation units, that is they are relatively cheap in mass and volume.

The limited lifting capacity and available volume make it necessary to carefully adjust the number of units included in a control system, among other things, because each individual node in the distributed system needs to be encapsulated and have reliable connectors, which in turn contributes to the weight and volume without having a useful function.

The control system can be modified in a number of ways within the scope of the invention such as defined by the following claims.

REFERENCE NUMERALS

1	Central control unit
2	Ports
3, 4	Communication buses/ring buses (one for actuators and one for sensors)
5	High performance attitude measuring sensor system
6	CPU, processor (the core of the calculation unit)
7	Low performance attitude measuring sensor system
8	Position measuring sensor system
9	Aerial
10	Short distance radio link
11	Calculation unit (comprises at least one processor 6 and possibly a short distance radio link 10)
12	Interface unit (comprises a low performance sensor system 7 and a position measuring sensor system 8)
13	Internal high-speed bus

14-17 relate to actuating means (examples given below for a UAV equipped with a rotor)

14	Tail rotor actuator
15	Main rotor actuator
16	Engine control actuator
17	Engine control unit

18-22 relate to sensors

18	Fuselage monitoring sensor (vibration monitor)
19	Landing sensor
20	Magnetic compass sensor
21	Air data sensor
22	Engine monitoring unit
23	Power supply
24	Payload
25	Ground communication unit

CLAIMS

1. A control system for unmanned vehicles, such as unmanned aerial vehicles, which system comprises a central control unit (1),
characterised in that

the central control unit (1) comprises the components which are the most critical for the control of the vehicle,

the system further comprises a plurality of actuating means (14, 15, 16, 17) and/or sensors (18, 19, 20, 21, 22) which are distributed externally of the central control unit (1), and

the distributed means (14, 15, 16, 17) and/or the sensors (18, 19, 20, 21, 22) communicate with each other and with the central control unit (1) via at least one bidirectional ring bus (3, 4), to which the means and/or the sensors are connected in series and which ring bus (3, 4) is connected to the central control unit (1) by at least two ports (2).

2. A control system as claimed in claim 1, wherein the components in the central control unit (1) which are the most critical for the control of the vehicle are at least one calculation unit (11), at least one attitude measuring sensor system (5, 7) and at least one position measuring sensor system (8).

3. A control system as claimed in claim 1 or 2, wherein the distributed means (14, 15, 16, 17) and/or the sensors (18, 19, 20, 21, 22) communicate with each other and with the central control unit (1) via two mutually independent bidirectional ring buses (3) and (4), which are connected to the central control unit (1) by four ports.

4. A control system as claimed in any one of claims 1-3, wherein the central control unit (1) comprises at least one high performance attitude measuring sensor system (5) and at least two low performance attitude measuring sensor systems (7).

5. A control system as claimed in any one of claims 1-4, wherein the central control unit (1) is designed such that the high performance attitude measuring sensor system (5) is located in the centre of the central control unit (1) and the at least two low performance attitude measuring sensor systems (7) are located on opposite sides of the high performance attitude measuring sensor system (5).

6. A control system as claimed in any one of claims 1-5, wherein the central control unit (1) comprises at least one interface unit (12), which comprises a low performance attitude measuring sensor system (7) and a position measuring sensor system (8) and through which interface unit (12) all power supply to all the distributed means (14, 15, 16, 17) and/or the sensors (18, 19, 20, 21, 22) passes to allow measuring of the power consumption, and which interface unit (12) is capable of disconnecting the power supply to the functions of the system that are not safety-critical, such as a payload (24).

7. A control system for unmanned vehicles, such as unmanned aerial vehicles, which system comprises a central control unit (1),
characterised in that
the central control unit (1) comprises the components which are the most critical for the control of the vehicle, the central control unit (1) comprises at least one high performance attitude measuring sensor system (5) and at least two interface units (12), each comprising at least one low performance attitude measuring sensor system (7) and at least one position measuring sensor system (8), and the central control unit (1) further comprises at least two calculation units (11) which are arranged to calculate the attitude and the position of the vehicle, and which units function independently of each other, but are capable of communicating with each other via an internal bus (13).

8. A control system as claimed in claim 7, wherein the central control unit (1) is designed such that the high performance attitude measuring sensor system (5) is located in the centre of the central control unit (1), and the at

least two low performance attitude measuring sensor systems (7), the at least two position measuring sensor systems (8) and the at least two calculation units (11) are located on opposite sides of the high performance attitude measuring sensor system (5).

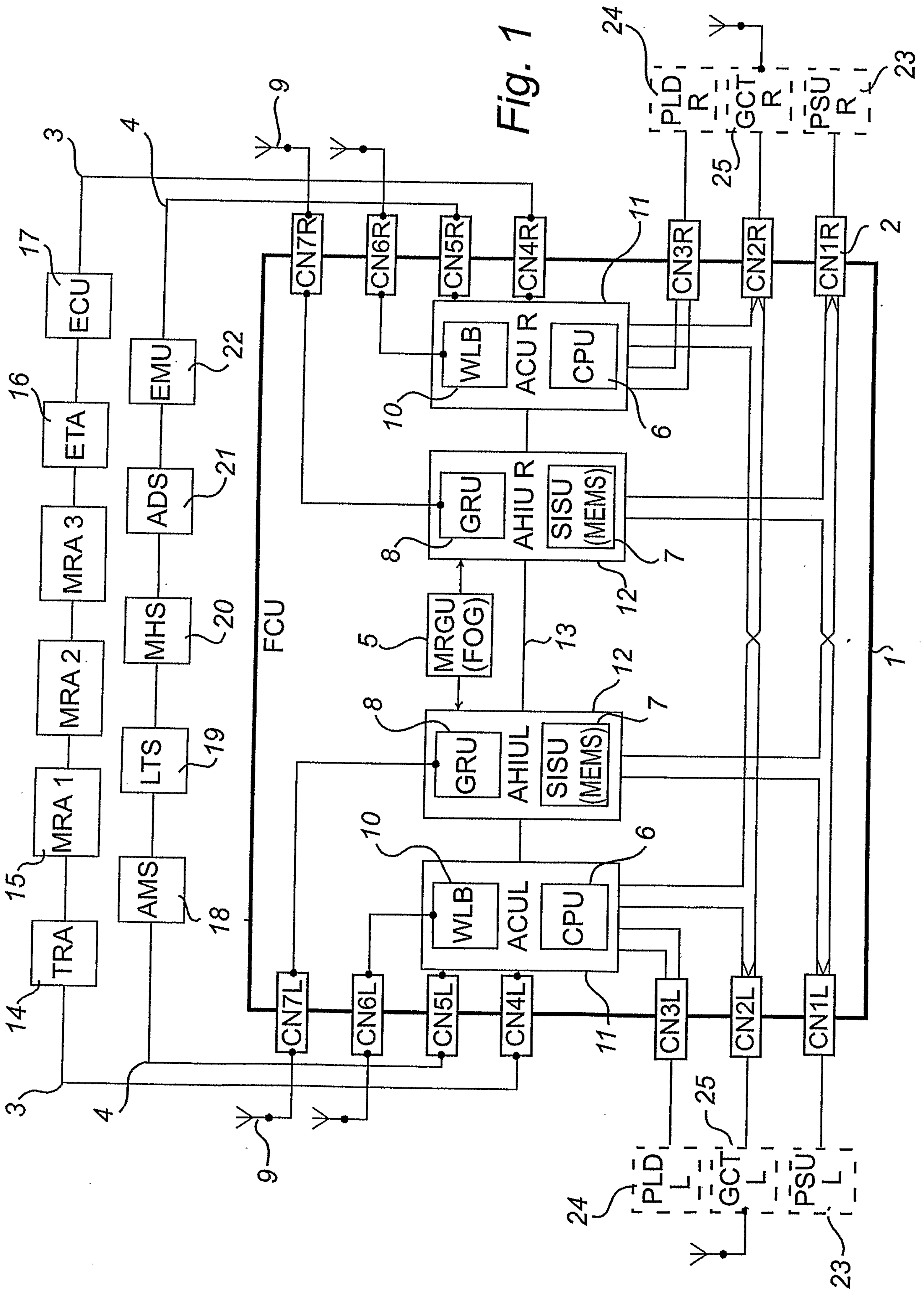

Fig. 1

TRA
MRA 1
MRA 2
MRA 3
ETA
ECU
AMS
LTS
MHS
ADS
EMU
FCU
MRGU (FOG)
ACUL
WLB
CPU
AHIUL
GRU
SISU (MEMS)
ACU R
AHIU R
CN1L
CN2L
CN3L
CN4L
CN5L
CN6L
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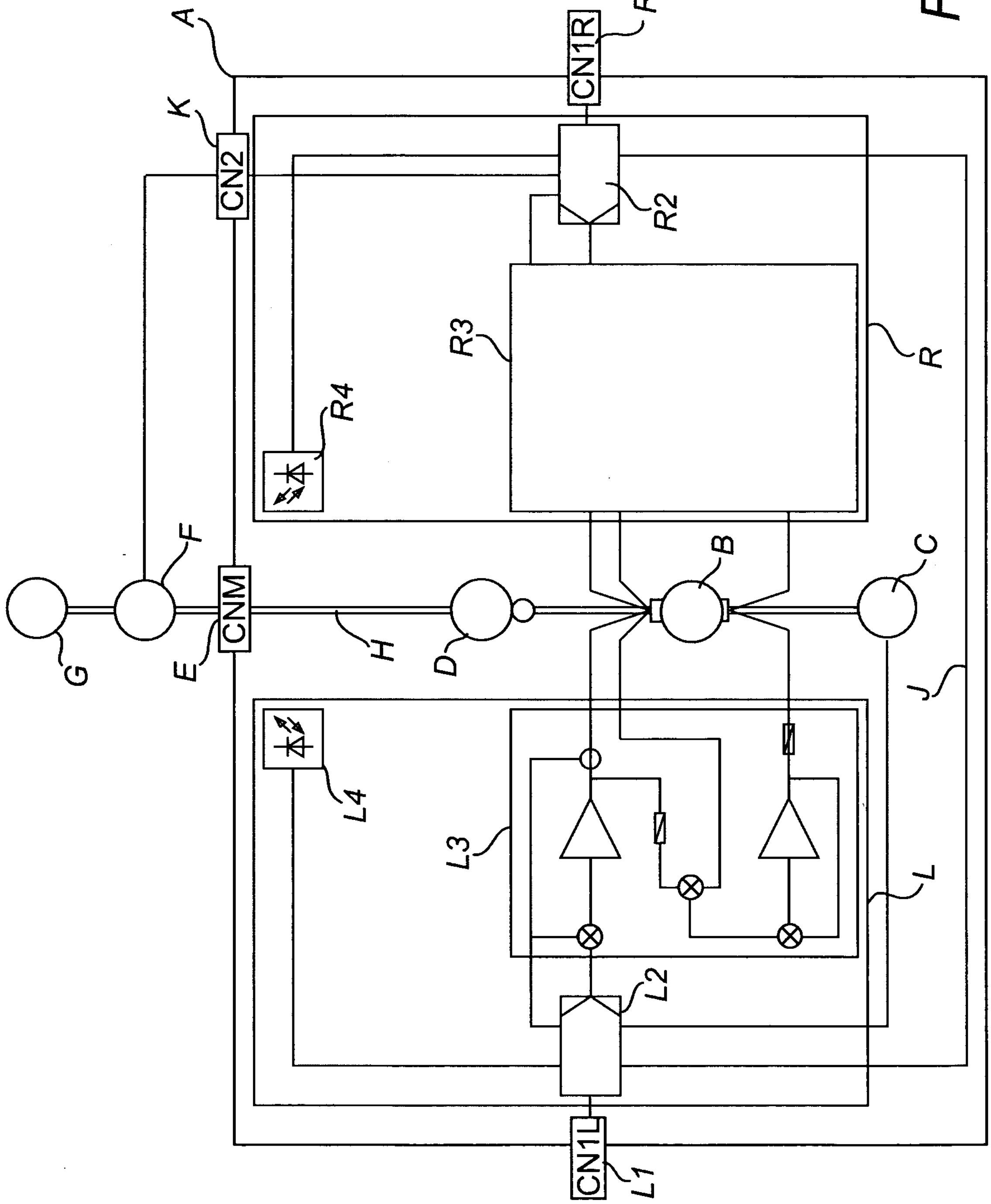

Fig. 2

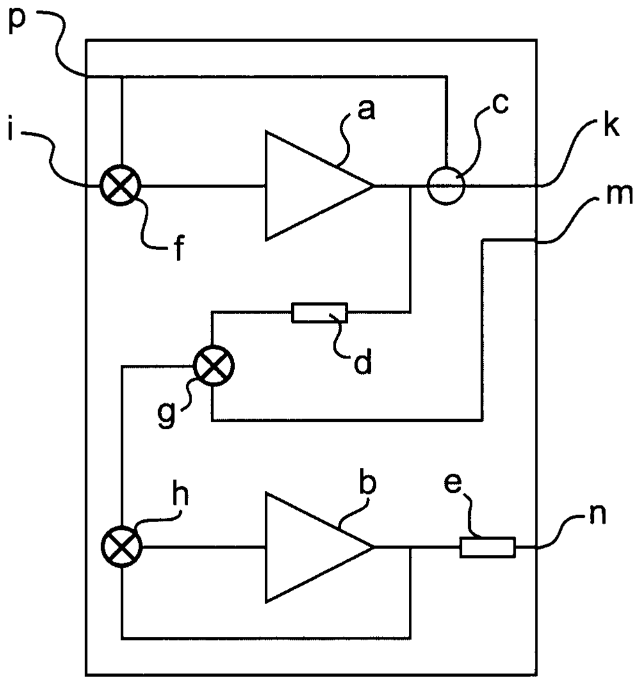

Fig. 3