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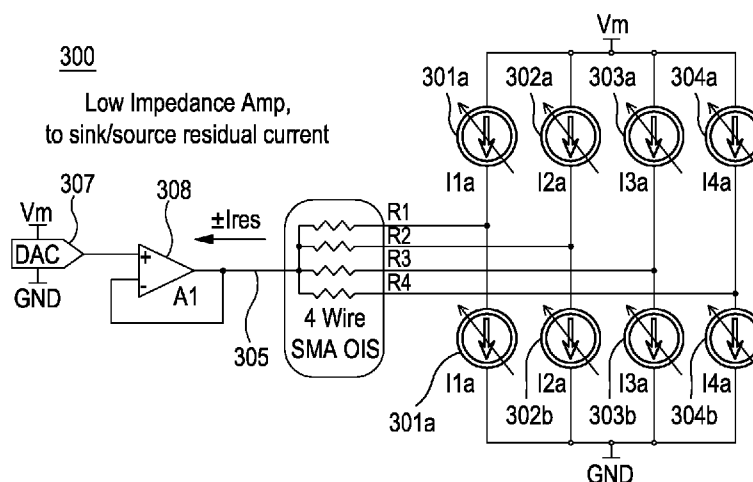


Figure 3

(57) Abstract: P405-WO0 19 Shape Memory Alloy Actuator Driver Arrangement ABSTRACT Disclosed is a circuit arrangement for delivering current to a shape memory alloy, SMA, actuator wire arrangement, comprising: a plurality of SMA actuator wires, each of the plurality of SMA actuator wires being connected to at least one of a current source and a current sink, wherein the plurality of SMA actuator wires share a common node arranged to be set at a voltage between a maximum supply voltage and a minimum supply voltage; and wherein at least one of the plurality of SMA actuator wires is connected to a current source and at least one other of the plurality of SMA actuator wires is connected to a current sink.



Shape Memory Alloy Actuator Driver Arrangement

The present application generally relates to delivering power to a shape memory alloy (SMA) actuator.

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The control of SMA actuators relies on knowing the resistance of the SMA actuator wires. The resistance of the wire effectively serves as a proxy for the length. Driving the wires of an SMA actuator with current sources provides a simple way to control precisely the power delivered to each wire, which makes it easier to determine the resistance of the SMA wires. However, it is typically very inefficient, which can cause problems, especially in mobile or portable devices which operate with limited power supplies e.g. batteries.

Figure 1 shows a plan view of an arrangement of shape memory alloy (SMA) actuator wires in an actuator 10. The actuator 10 may be incorporated into any apparatus comprising at least one component that requires moving during operation. For example, the actuator 10 may be used to move an optical element of an image capture device, but this is a non-limiting example. The actuator 10 may be incorporated into, for example, a smartphone, a mobile computing device, a laptop, a tablet computing device, a security system, a gaming system, an augmented reality system, an augmented reality device, a wearable device, a medical device, a drug delivery device, a drone (aerial, water, underwater, etc.), a vehicle (e.g. a car, an aircraft, a spacecraft, a submersible vessel, etc.), and an autonomous vehicle. It will be understood this is a non-exhaustive list of example devices into which the present actuator may be incorporated. In some cases, miniaturisation may be an important design criterion for the actuator.

The actuator 10 may, in use, comprise a component 2 that requires moving. The component 2 may be supported on a support structure 4 by a suspension system, in a manner allowing movement of the component 2 relative to the support structure 4 in two orthogonal directions each perpendicular to the primary axis P. In operation, the component 2 may be moved orthogonally to the primary axis P in two orthogonal directions, shown as X and Y.

The actuator 10 may, in embodiments, comprise four shape memory alloy (SMA) actuator wires 11 to 14 that are each connected to support structure 4 and to a movable component 15 that is used move the component 2 that requires moving. (It will be understood that this is just one example arrangement of an SMA actuator – the present techniques apply to an actuator having at least two SMA actuator wires). Each of the SMA actuator wires 11 to 14 is held in tension, thereby applying a force between the movable platform 15 and the support block 16 in a direction perpendicular to the primary axis P. In operation, the SMA actuator wires 11 to 14 move component 2 relative to the support block 16 in two orthogonal directions perpendicular to the primary axis P. The SMA actuator wires 11 to 14 each extend perpendicular to the primary axis P. In this actuator 10, the SMA actuator wires 11 to 14 may extend in a common plane, which may be advantageous in minimising the size of the actuator 10 along the primary axis P (e.g. the overall height or depth of the actuator 10).

Irrespective of whether the SMA actuator wires 11 to 14 are perpendicular to the primary axis P or inclined at a small angle to the plane perpendicular to the primary axis P, the actuator 10 may be made very compact, particularly in the direction along the primary axis P. The SMA actuator wires 11 to 14 may be, in some embodiments, very thin, typically of the order of 25µm in diameter, to ensure rapid heating and cooling. The arrangement of SMA actuator wires 11 to 14 may not add to the footprint of the actuator 10 and may be made very thin in the direction along the primary axis P, since the SMA actuator wires 11 to 14 are laid essentially in a plane perpendicular to the primary axis P in which they remain in operation. The height along the primary axis may then depend on the thickness of the other components such as crimping members 17 and 18, and on the height necessary to allow manufacture. In practice, it has been found that the actuator arrangement of SMA actuator wires 11 to 14 may be manufactured to a height of less than 1mm. In the example of a smartphone camera, the size of the SMA actuator wires 11 to 14 typically restricts the angle between the SMA actuator wires 11 to 14 and the plane perpendicular to the primary axis P to be less than 20 degrees, and more preferably less than 10 degrees.

The SMA actuator wires 11 to 14 are connected at one end to the movable platform 15 by respective crimping members 17 and at the other end to the support block 16 by crimping members 18. The crimping members 17 and 18 crimp the wire to hold it mechanically, optionally strengthened by the use of adhesive. The crimping members 17 and 18 also provide an electrical connection to the SMA actuator wires 11 to 14. However, any other suitable means for connecting the SMA actuator wires 11 to 14 may alternatively be used.

SMA material has the property that on heating it undergoes a solid-state phase change which causes the SMA material to contract. On heating of one of the SMA actuator wires 11 to 14, the stress therein increases and it contracts. This causes movement of the component 2. Conversely, on cooling of one of the SMA actuator wires 11 to 14 so that the stress therein decreases, it expands under the force from opposing ones of the SMA actuator wires 11 to 14. This allows the component 2 to move in the opposite direction.

As shown in Figure 1, the SMA actuator wires 11 to 14 have an arrangement around the primary axis P as follows. Each of the SMA actuator wires 11 to 14 is arranged along one side of the component 2. Thus, the SMA actuator wires 11 to 14 are arranged in a loop at different angular positions around the primary axis P. Thus, the four SMA actuator wires 11 to 14 consist of a first pair of SMA actuator wires 11 and 13 arranged on opposite sides of the primary axis P and a second pair of SMA actuator wires 12 and 14 arranged on opposite sides of the primary axis P. The first pair of SMA actuator wires 11 and 13 are capable on selective driving to move the component 2 relative to the support structure 4 in a first direction in said plane, and the second pair of SMA actuator wires 12 and 14 are capable on selective driving to move the component 2 relative to the support structure 4 in a second direction in said plane transverse to the first direction. Movement in directions other than parallel to the SMA actuator wires 11 to 14 may be driven by a combination of actuation of these pairs of the SMA actuator wires 11 to 14 to provide a linear combination of movement in the transverse directions. Another way to view this movement is that simultaneous contraction of any pair of the SMA actuator wires 11 to 14 that are adjacent each other in the loop will drive movement of the component 2 in a direction bisecting those two of the SMA

actuator wires 11 to 14 (diagonally in Figure 1, as labelled by the arrows X and Y).

As a result, the SMA actuator wires 11 to 14 are capable of being selectively driven to move the component 2 relative to the support structure 4 to any position in a range of movement in two orthogonal directions perpendicular to the primary axis P. The magnitude of the range of movement depends on the geometry and the range of contraction of the SMA actuator wires 11 to 14 within their normal operating parameters.

The position of the component 2 relative to the support structure 4 perpendicular to the primary axis P is controlled by selectively varying the temperature of the SMA actuator wires 11 to 14. This is achieved by passing through SMA actuator wires 11 to 14 selective drive currents that provides resistive heating. Heating is provided directly by the drive current. Cooling is provided by reducing or ceasing the drive current to allow the component 2 to cool by conduction, convection and radiation to its surroundings.

Figure 2 shows a simple current driver topology 200 for driving SMA actuator wires R1, R2, R3, R4 in an actuator. This topology 200 represents the current state of the art. The topology 200 comprises four SMA actuator wires that can be modelled as R1, R2, R3, R4, four current sinks 201, 202, 203, 204 to drive (in the sense that they sink current from), respectively, SMA actuator wires R1, R2, R3 and R4, and four digital-to-analogue converters (DAC) 211, 212, 213 and 214 to control the operation of respective current sinks 201, 202, 203 and 204.

The four SMA actuator wires R1, R2, R3, R4 correspond, respectively, to SMA actuator wires 11, 13, 12, 14, as shown in Figure 1. In other words, wires 11 and 13 are substantially opposite each other and wires 12 and 14 are substantially opposite each other. The voltage at the common node of the SMA actuator wires 205 has a value of power supply voltage (VM) in this case. The VM value corresponds to the maximum value of the voltage provided by a power supply e.g. a battery.

Each current sink 201, 202, 203, 204 is connected to a single SMA wire in the four SMA actuator wire arrangement R1, R2, R3, R4 and to the ground (GND). Thus, each wire from the arrangement of four SMA wires R1, R2, R3, R4 is driven with a current sink to the ground. In many practical applications, each SMA wire from the arrangement of SMA wires R1, R2, R3, R4 requires an approximately similar current to drive the actuator. In this topology 200, the current required to drive the entire actuator equals the sum of all currents from the current sinks 201, 202, 203, 204. In other words, $I_{total} = I_1 + I_2 + I_3 + I_4$.

DACs 211, 212, 213 and 214 are operable to control the respective current sinks 201, 202, 203, 204 by converting a digital control signal into an analogue signal.

A problem with the driver topology of Figure 2 is that it is relatively inefficient because a large amount of power is dissipated by the current sinks 201, 202, 203 and 204, given a fixed voltage supply, V_M . An aim of embodiments of the present techniques is to address this and other shortcomings in the prior art, whether identified herein or not.

According to a first approach of the present techniques, there is provided a circuit arrangement for delivering current to a shape memory alloy, SMA, actuator wire arrangement, comprising: a plurality of SMA actuator wires, each of the plurality of SMA actuator wires being connected to at least one of a current source and a current sink, wherein the plurality of SMA actuator wires share a common node arranged to be set at a voltage between a maximum supply voltage and a minimum supply voltage; and wherein at least one of the plurality of SMA actuator wires is connected to a current source and at least one other of the plurality of SMA actuator wires is connected to a current sink.

The voltage at the common node may be arranged to be variable.

The voltage at the common node may be set by means of an amplifier and a Digital to Analog Convertor, DAC.

Each of the plurality of SMA actuator wires may be connected to a current source and a current sink.

5 In an embodiment, only the current source or only the current sink may be operable at any given time.

The plurality of SMA actuator wires may be arranged as pairs of two wires, wherein each wire in a first pair, in use, receives current from a current source and wherein each wire in a second pair, in use, sources current to a current sink.
10

The circuit arrangement may comprise a feedback mechanism operable to monitor current provided or sunk by respective current sources and current sinks and to determine if the current sources and current sinks are nearing a saturation limit and to vary the voltage at the common node in response to the
15 determination.

According to a further approach of the present techniques, there is provided a method of operating the circuit arrangement of any preceding claim comprising the steps of: determining a voltage at the common node; determining
20 a first pair of SMA actuator wires; determining a second pair of SMA actuator wires; providing at least two current sources to source current to wires in the first pair of SMA actuator wires; providing at least two current sinks to sink current from wires in the second pair of SMA actuator wires; delivering current to the first pair of SMA actuator wires in a first direction and delivering current to the second
25 pair of SMA actuator wires in a second direction, opposite to the first direction.

The circuit arrangement and the SMA actuator wire arrangement may be used to control any type of device that comprises a static part and a moveable part which is moveable with respect to the static part. The circuit arrangement
30 and SMA actuator wire arrangement/assembly may be provided in any one of the following devices: a smartphone, a camera, a foldable smartphone, a foldable image capture device, a foldable smartphone camera, a foldable consumer electronics device, a camera with folded optics, an image capture device, an array camera, a 3D sensing device or system, a servomotor, a consumer electronic

device (including domestic appliances such as vacuum cleaners, washing machines and lawnmowers), a mobile or portable computing device, a mobile or portable electronic device, a laptop, a tablet computing device, an e-reader (also known as an e-book reader or e-book device), a computing accessory or
5 computing peripheral device (e.g. mouse, keyboard, headphones, earphones, earbuds, etc.), an audio device (e.g. headphones, headset, earphones, etc.), a security system, a gaming system, a gaming accessory (e.g. controller, headset, a wearable controller, joystick, etc.), a robot or robotics device, a medical device (e.g. an endoscope), an augmented reality system, an augmented reality device,
10 a virtual reality system, a virtual reality device, a wearable device (e.g. a watch, a smartwatch, a fitness tracker, etc.), a drone (aerial, water, underwater, etc.), an aircraft, a spacecraft, a submersible vessel, a vehicle, an autonomous vehicle (e.g. a driverless car), a tool, a surgical tool, a remote controller (e.g. for a drone or a consumer electronics device), clothing (e.g. a garment, shoes, etc.), a switch,
15 dial or button (e.g. a light switch, a thermostat dial, etc.), a display screen, a touchscreen, and a near-field communication (NFC) device. It will be understood that this is a non-exhaustive list of example devices.

The circuit arrangement and the SMA actuator wire arrangement
20 described herein may be used in devices/systems suitable for image capture, 3D sensing, depth mapping, aerial surveying, terrestrial surveying, surveying in or from space, hydrographic surveying, underwater surveying, scene detection, collision warning, security, facial recognition, augmented and/or virtual reality, advanced driver-assistance systems in vehicles, autonomous vehicles, gaming,
25 gesture control/recognition, robotic devices, robotic device control, touchless technology, home automation, medical devices, and haptics.

In a related approach of the present techniques, there is provided a non-transitory data carrier carrying processor control code to implement any of the
30 methods described herein.

As will be appreciated by one skilled in the art, the present techniques may be embodied as a system, method or computer program product. Accordingly, present techniques may take the form of an entirely hardware embodiment, an

entirely software embodiment, or an embodiment combining software and hardware aspects.

Furthermore, the present techniques may take the form of a computer
5 program product embodied in a computer readable medium having computer
readable program code embodied thereon. The computer readable medium may
be a computer readable signal medium or a computer readable storage medium.
A computer readable medium may be, for example, but is not limited to, an
electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system,
10 apparatus, or device, or any suitable combination of the foregoing.

Computer program code for carrying out operations of the present
techniques may be written in any combination of one or more programming
languages, including object oriented programming languages and conventional
15 procedural programming languages. Code components may be embodied as
procedures, methods or the like, and may comprise sub-components which may
take the form of instructions or sequences of instructions at any of the levels of
abstraction, from the direct machine instructions of a native instruction set to
high-level compiled or interpreted language constructs.

20

Embodiments of the present techniques also provide a non-transitory data
carrier carrying code which, when implemented on a processor, causes the
processor to carry out any of the methods described herein.

25 The techniques further provide processor control code to implement the
above-described methods, for example on a general purpose computer system or
on a digital signal processor (DSP). The techniques also provide a carrier carrying
processor control code to, when running, implement any of the above methods,
in particular on a non-transitory data carrier. The code may be provided on a
30 carrier such as a disk, a microprocessor, CD- or DVD-ROM, programmed memory
such as non-volatile memory (e.g. Flash) or read-only memory (firmware), or on
a data carrier such as an optical or electrical signal carrier. Code (and/or data) to
implement embodiments of the techniques described herein may comprise source,
object or executable code in a conventional programming language (interpreted

or compiled) such as C, or assembly code, code for setting up or controlling an ASIC (Application Specific Integrated Circuit) or FPGA (Field Programmable Gate Array), or code for a hardware description language such as Verilog (RTM) or VHDL (Very high speed integrated circuit Hardware Description Language). As the skilled person will appreciate, such code and/or data may be distributed between a plurality of coupled components in communication with one another. The techniques may comprise a controller which includes a microprocessor, working memory and program memory coupled to one or more of the components of the system.

It will also be clear to one of skill in the art that all or part of a logical method according to embodiments of the present techniques may suitably be embodied in a logic apparatus comprising logic elements to perform the steps of the above-described methods, and that such logic elements may comprise components such as logic gates in, for example a programmable logic array or application-specific integrated circuit. Such a logic arrangement may further be embodied in enabling elements for temporarily or permanently establishing logic structures in such an array or circuit using, for example, a virtual hardware descriptor language, which may be stored and transmitted using fixed or transmittable carrier media.

In an embodiment, the present techniques may be realised in the form of a data carrier having functional data thereon, said functional data comprising functional computer data structures to, when loaded into a computer system or network and operated upon thereby, enable said computer system to perform all the steps of the above-described method.

Implementations of the present techniques will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows a typical SMA actuator arrangement known in the art;

Figure 2 shows a current driver topology for driving SMA actuator wires according to the prior art;

Figure 3 shows a general arrangement of a current driver topology for driving SMA actuator wires in an actuator according to an embodiment of the present techniques;

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Figure 4 shows a general arrangement of a current driver topology for driving SMA actuator wires in an actuator according to another embodiment of the present techniques;

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Figure 5 shows a general arrangement of a current driver topology for driving SMA actuator wires in an actuator according to a still further embodiment of the present techniques; and.

15

Figure 6 shows a block diagram of a method of controlling drive signals supplied to SMA actuator wires in an SMA actuation arrangement according to an embodiment of the present techniques.

20

In the following description, reference is made to both current sources and current sinks. The skilled person will understand that the underlying arrangement and techniques for each are the same or similar and whether a particular arrangement is a source or a sink is largely a matter of terminology. As such, when reference is made herein to source/sourcing, this can mean sink/sinking, as appropriate. The context will dictate the appropriate terminology. In particular, if reference is made to a sink driving an SMA actuator wire, the skilled person will realize that, in fact, the SMA actuator wire is providing current to the sink, but in order to avoid an over-complicated description, this will be referred to as the sink driving the SMA actuator wire.

25

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Figure 3 shows a general arrangement of a current driver topology 300 for driving SMA actuator wires R1, R2, R3, R4 in an actuator according to an embodiment of the present techniques. This topology 300 comprises four SMA actuator wires R1, R2, R3, R4, four current sources 301a, 302a, 303a, 304a, four current sinks 301b, 302b, 303b, 304b, a digital-to-analog converter (DAC) 307, and an amplifier 308. Four SMA actuator wires R1, R2, R3, R4 correspond to

respective SMA actuator wires 11, 13, 12, 14 in Figure 1. A voltage at the common node of the SMA actuator wires 305 can take any value from a range between ground (GND) and the power supply voltage (VM), as set by the DAC 307. The VM value corresponds to the maximum value of voltage provided by a power supply.

- 5 The GND voltage corresponds to the minimum value of voltage provided by the power supply. In some embodiments, the maximum and minimum voltages may have any positive or negative polarity or be zero.

Each SMA actuator wire from the four SMA actuator wire arrangement R1, R2, R3, R4 is connected to one current source 301a, 302a, 303a, 304a and to one current sink 301b, 302b, 303b, 304b. Each current sink 301b, 302b, 303b, 304b is connected to a single SMA wire in the four SMA actuator wire arrangement R1, R2, R3, R4, to the ground (GND), and to one of the current sources 301a, 302a, 303a, 304a. Each current source 301a, 302a, 303a, 304a is connected to a single SMA wire in the four SMA actuator wire arrangement R1, R2, R3, R4 to power supply voltage (VM), and to one of the current sinks 301b, 302b, 303b, 304b.

The four wires of the SMA actuator wire arrangement R1, R2, R3, R4 have a common node 305. The common node 305 is connected to the output of an amplifier 308. The amplifier 308 may be a low impedance amplifier. The amplifier may be configured to pass a residual current (+/- Ires) from the common node of the SMA actuator wires 305 to the ground (GND), or to the power supply (VM), or to DAC 307. DAC 307 is connected to the amplifier 308 for converting a digital signal into an analogue signal, for forcing a voltage at a common node of the SMA actuator wires 305 to any voltage in a range between ground voltage and power supply voltage, VM.

The general arrangement 300 enables each wire from the arrangement of four SMA actuator wires R1, R2, R3, R4 to be driven by one of the current sinks 301b, 302b, 303b, 304b or by one of the current sources 301a, 302a, 303a, 304a. The SMA actuator wires R1, R2, R3, R4 may be regarded as two pairs, with each of the two pairs comprising two wires. In a given pair, the two wires are arranged substantially physically opposite each other. For instance, by reference to Figure

1, a first pair comprises wires 11 (R1) and 13, (R2) and a second pair comprises wires 12 (R3) and 14 (R4).

5 The general arrangement 300 provides at least two current sources from available current sources 301a, 302a, 303a, 304a for delivering current to a first pair of SMA actuator wires and at least two current sinks from available current sinks 301b, 302b, 303b, 304b for sinking current from a second pair of SMA actuator wires. This has the advantageous effect of reducing the overall current flow by, in most cases, a factor of 2. This has a consequent effect on power
10 consumption also.

In order to illustrate this, reference is made to Figure 4 which shows a specific configuration of the general form of Figure 3.

15 In Figure 4, the common node voltage 405 is set to halfway between the maximum and minimum supply voltages i.e. $V_M/2$. For the purposes of this example, consider that the common node voltage is fixed. By providing a pair of current sources 401, 402 to supply current to R1 and R2 respectively and a pair of current sinks 403, 404 to sink current from R3 and R4 respectively, it can be
20 seen that current flows through R1 and R2 in a direction from V_M to the common node 405 (right to left as seen in Figure 4). In the case of R3 and R4, current flows from the common node towards GND (left to right as seen in Figure 4).

25 If the current flowing in each SMA actuator wire is approximately equal (as is usually the case), then the overall current flow can thus be seen to be twice the current flowing in any one SMA actuator wire, meaning that total current is substantially half that flowing in the prior art arrangement of Figure 2.

30 The arrangement of Figure 4 is intended to illustrate the general point that when the SMA actuator wires are arranged as pairs, then one pair is associated with current sources and the other pair is associated with current sinks.

Returning to Figure 3, it can be seen that by selectively controlling current sources 301a-304a and current sinks 301b-304b, such that each SMA actuator

wire either only receives current from a current source or only supplies current to a current sink, the benefits of reduced current flow – and so reduced power consumption – as illustrated in Figure 4 can be realized.

5 In a specific example, SMA actuator wires R1 and R2 may be supplied current from current sources 301a and 302a, while SMA actuator wires R3 and R4 supply current to current sinks 303b and 304b, Current sources 303a and 304a, as well as current sinks 301b and 302b are effectively out of circuit. This can be achieved by their respective DAC controllers (not shown, but see DACs 211-214
10 in Figure 2)

Figure 5 illustrates an enhancement to the arrangement of Figure 3. The basic arrangement is as shown in Figure 3, but with the addition of a feedback circuit or servo controller 509. In this case, each of the current sources and current
15 sinks is monitored for saturation. In order to detect saturation, different approaches may be utilised. In a first approach, a current source typically requires a minimum voltage drop across it to properly regulate current. By measuring this voltage drop and comparing it to a predefined threshold, a saturation or near-saturation condition may be detected. In a second approach, if the current source
20 uses a current-sense mechanism to control a servo or feedback loop, then the sensed current may be compared to a requested current to determine if the current source is in saturation or near-saturation.

The results of this monitoring are fed into a Bias Voltage Servo Controller
25 509 which, upon determining that one or more current sources or current sinks is in or near saturation, act to adjust the common node voltage by means of sending a control word to the DAC, thereby changing the output of the amplifier. The Bias Voltage Servo Controller 509 can be implemented as a software routine in a controller (not shown), as a standalone digital circuit or a standalone analogue
30 circuit.

By altering the common node voltage, it is possible to draw more current in one or more of the SMA actuator wires. As an extreme example to illustrate this point, assume that the Bias Voltage Servo Controller 509 sends a control word to

DAC such that the common node voltage is set to its maximum value V_M . In such a case, only current sinks 301b-304b are active and the total current flowing will be approximately 4 times the current flowing in any one wire. This scenario is similar to the prior art configuration as shown in Figure 2. It illustrates the flexibility of embodiments of the present techniques, whereby in a first mode of operation, substantial current and so, power, savings can be achieved, whereas if more current is required, this can be achieved only as and when needed. This can result in significant power savings overall.

Figure 6 shows a method 600 of controlling drive signals supplied to SMA actuator wires in an SMA actuation arrangement according to an embodiment of the present techniques. In this method 600, the SMA actuator wires are arranged in pairs as has been described. Also, in this method 600, the SMA actuator wires in a given pair are arranged substantially physically opposite each other.

Figure 6 shows a flowchart of steps associated with controlling drive signals supplied to SMA actuator wires in an SMA actuation arrangement. The method 600 starts with the determination of the voltage on the common node of the SMA wires in an SMA actuation arrangement in step 601. This can be achieved by, for example, a servo controller. An initial default value (e.g. a midpoint) can be defined as a starting voltage.

In step 602, a first pair of SMA actuator wires is determined. This determination is based on a physical arrangement of the SMA wires in an SMA actuator. In particular, SMA wires positioned substantially physically opposite each other form the first pair.

In step 603, a second pair of SMA actuator wires is determined. This determination is based on a physical arrangement of the SMA wires in an SMA actuator. In particular, SMA wires positioned substantially physically opposite each other form the second pair. The person skilled in the art will appreciate that more than two pairs can be determined based on the number of SMA wires in a particular SMA actuator.

In step 604, at least two current sources for delivering current to the first pair of SMA actuator wires are provided. This step may involve disabling or otherwise controlling any current sinks associated with the first pair of SMA actuator wires.

5

In step 605, at least two current sinks for sinking current from the second pair of SMA actuator wires are provided. This step may involve disabling or otherwise controlling any current sources associated with the second pair of SMA actuator wires.

10

The effect of steps 604 and 605 is that the actuator arrangement as a whole makes use of both current sinks and current sources, which serves to deliver the reduction in current which is achieved.

15

In step 606, current is delivered to the two pairs of SMA actuator wires, such the current in one pair flows in an opposite direction to the current flowing in the other pair (relative to the common node).

20

In the foregoing, reference has been made to a 4-wire SMA actuator assembly, but it will be appreciated that this is exemplary only and in practice, any number of wires can be driven by using additional current sources and sinks.

25

Embodiments of the present techniques, as set out herein deliver the benefits described. In particular, the reduction in current leads directly to a reduction in power consumption overall, a matter of concern in portable devices having limited power capacity.

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In spite of the reduced power consumption possible, it is possible to boost the current flowing in any one or more SMA actuator wires by varying a common node voltage. This can be useful in e.g. lower ambient temperature operation of the device.

Those skilled in the art will appreciate that while the foregoing has described what is considered to be the best mode and where appropriate other

modes of performing present techniques, the present techniques should not be limited to the specific configurations and methods disclosed in this description of the preferred embodiment. Those skilled in the art will recognise that present techniques have a broad range of applications, and that the embodiments may
5 take a wide range of modifications without departing from any inventive concept as defined in the appended claims.

CLAIMS

1. A circuit arrangement for delivering current to a shape memory alloy, SMA, actuator wire arrangement, comprising:
 - 5 a plurality of SMA actuator wires, each of the plurality of SMA actuator wires being connected to at least one of a current source and a current sink, wherein the plurality of SMA actuator wires share a common node arranged to be set at a voltage between a maximum supply voltage and a minimum supply voltage; and
 - 10 wherein at least one of the plurality of SMA actuator wires is connected to a current source and at least one other of the plurality of SMA actuator wires is connected to a current sink.
2. The circuit arrangement of claim 1 wherein the voltage at the common node
15 is arranged to be variable.
3. The circuit arrangement of claim 2 wherein the voltage at the common node is set by means of an amplifier and a Digital to Analog Convertor, DAC.
- 20 4. The circuit arrangement of any preceding claim wherein each of the plurality of SMA actuator wires is connected to a current source and a current sink.
5. The circuit arrangement of claim 4 wherein only the current source or only the current sink is operable at any given time.
25
6. The circuit arrangement of any preceding claim wherein the plurality of SMA actuator wires are arranged as pairs of two wires, wherein each wire in a first pair, in use, receives current from a current source and wherein each wire in a second pair, in use, sources current to a current sink.
30
7. The circuit arrangement of any of claims 2 to 6 further comprising a feedback mechanism operable to monitor current provided or sunk by respective current sources and current sinks and to determine if the current sources and current

sinks are nearing a saturation limit and to vary the voltage at the common node in response to the determination.

8. A method of operating the circuit arrangement of any preceding claim
5 comprising the steps of:
- determining a voltage at the common node;
 - determining a first pair of SMA actuator wires;
 - determining a second pair of SMA actuator wires;
 - providing at least two current sources to source current to wires in the
10 first pair of SMA actuator wires;
 - providing at least two current sinks to sink current from wires in the
second pair of SMA actuator wires;
 - delivering current to the first pair of SMA actuator wires in a first direction
and delivering current to the second pair of SMA actuator wires in a second
15 direction, opposite to the first direction.
9. A non-transitory data carrier carrying control code to implement the method
of claim 8.

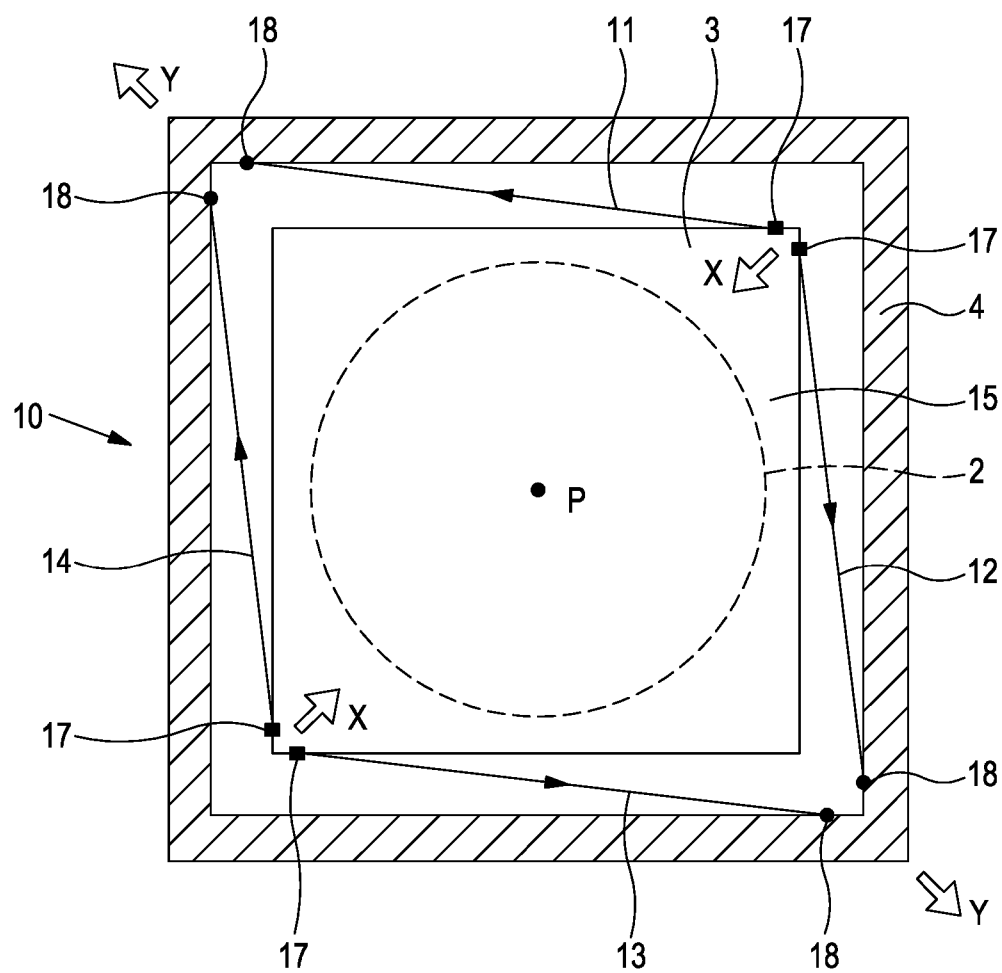


Figure 1

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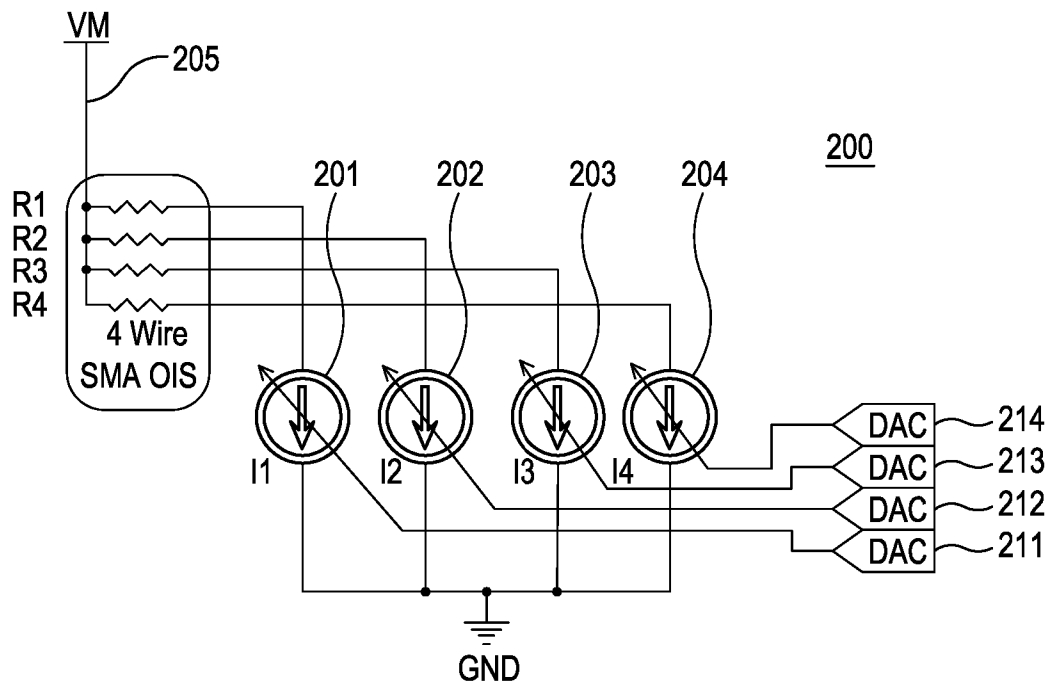


Figure 2

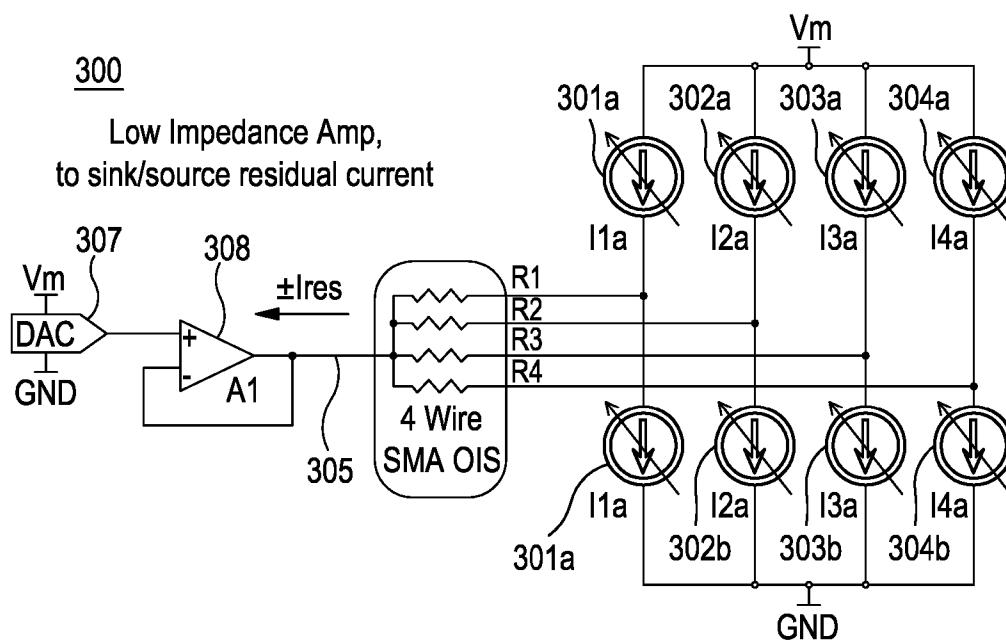


Figure 3

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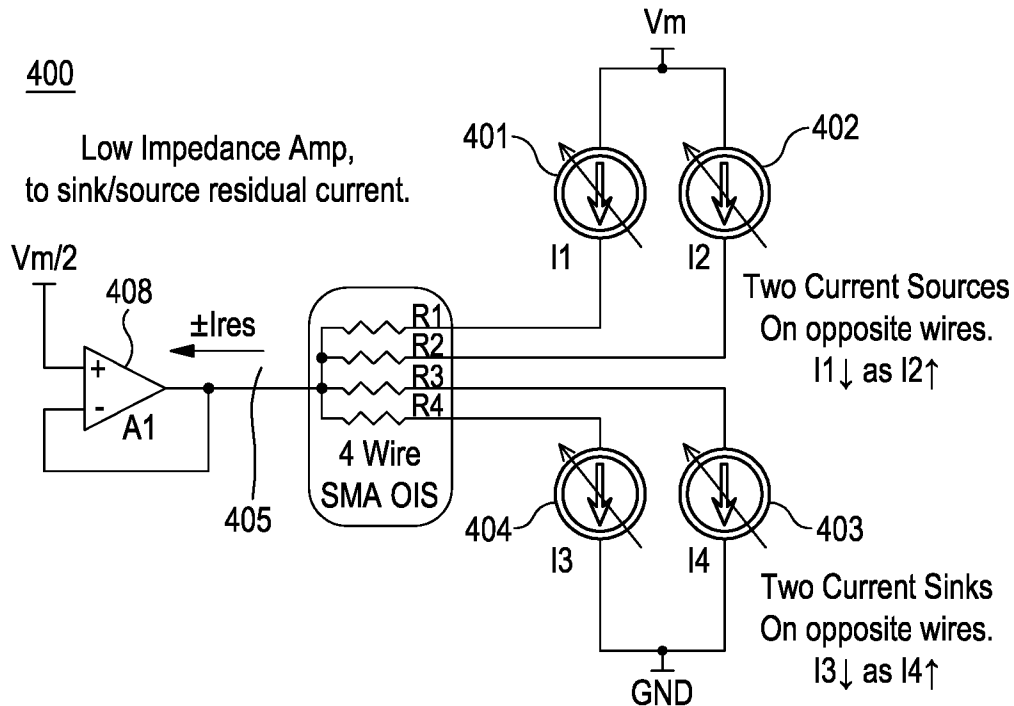


Figure 4

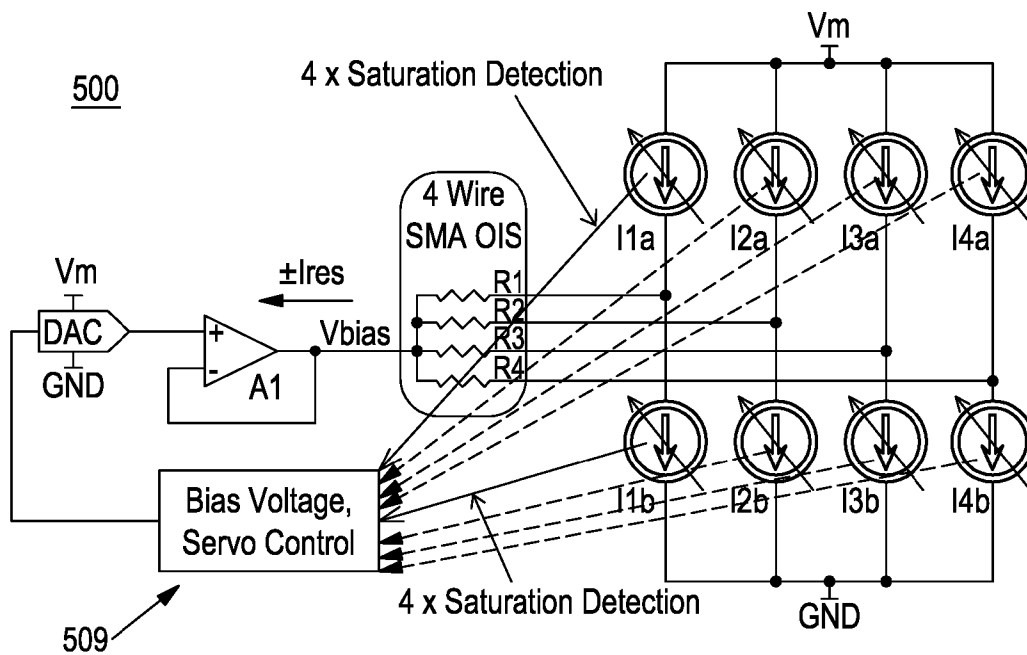


Figure 5

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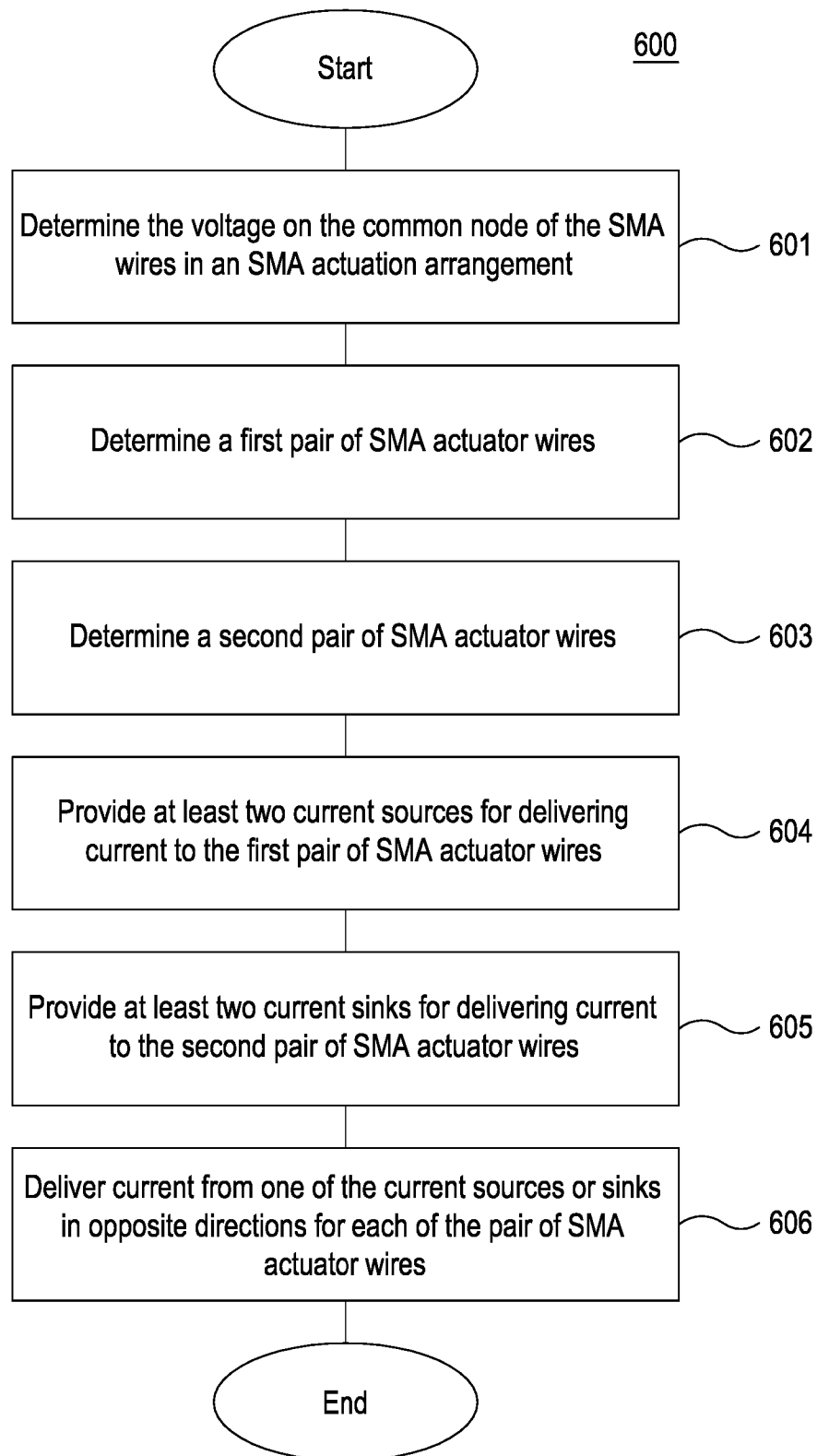


Figure 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2019/053430

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03G7/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03G G03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/300880 A1 (BROWN ANDREW BENJAMIN DAVID [GB] ET AL) 14 November 2013 (2013-11-14) paragraphs [0032], [0104]; figure 8 -----	1-9
A	WO 2012/020212 A1 (CAMBRIDGE MECHATRONICS LTD [GB]; TOPLISS RICHARD [GB] ET AL.) 16 February 2012 (2012-02-16) page 23, line 32 - page 26, line 33; figures 20-21 -----	1-9
A	WO 2013/121225 A1 (CAMBRIDGE MECHATRONICS LTD [GB]) 22 August 2013 (2013-08-22) page 12, line 28 - page 15, line 5; figures 5,6 -----	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

13 February 2020

Date of mailing of the international search report

28/02/2020

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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			WO 2013121225 A1 22-08-2013
