



(51) International Patent Classification:

A61N 1/04 (2006.01) A61N 1/36 (2006.01)

(21) International Application Number:

PCT/EP2018/073452

(22) International Filing Date:

31 August 2018 (31.08.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

17188784.7 31 August 2017 (31.08.2017) EP

(71) Applicant: **UNIVERSITY OF COPENHAGEN**
[DK/DK]; Norregade 10, 1165 Copenhagen K (DK).

(72) Inventors: **STROHMEIER, Paul**; Grundsteingasse
32-13, 1160 Wien (AT). **BORING, Sebastian**; Gartner-
gade 17, 4. th., 2200 Copenhagen N (DK). **HORNBAEK,**
Kasper; Elsevej 15, 3500 Værløse (DK). **KNIBBE, Jar-**
rod; U1 98 Bay Road, Sandringham, VIC 3191, Melbourne
(AU).

(74) Agent: **HØIBERG P/S**; Adelgade 12, 1304 Copenhagen K
(DK).

(81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,

CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every
kind of regional protection available*): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— of inventorship (*Rule 4.17(iv)*)

Published:

— with international search report (*Art. 21(3)*)

(54) Title: A GARMENT FABRIC FOR READING AND WRITING MUSCLE ACTIVITY

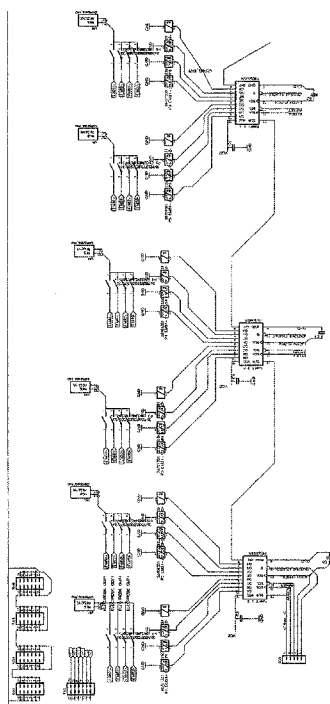


Fig. 8

(57) Abstract: The invention regards a wearable garment fabric for electric muscle stimulation (EMS) comprising: - an array of electrodes, wherein the electrodes are configured for multi-channel electromyography (EMG) and multi-channel EMS pulses, - an EMG control system configured for collecting EMG data within the electrode array when the fabric wearer makes a muscle(s) pose, and - an EMS control system configured for generating EMS pulses within the electrode array to replay the muscle(s) pose, wherein the EMS pulses are calibrated based on the collected and processed EMG data.

A garment fabric for reading and writing muscle activity

Field of invention

5 The present invention relates to a wearable garment fabric for electric muscle stimulation (EMS), a circuit for multiplexing EMG and EMS signals from an array of electrodes, a method for calibrating EMS for a muscle(s) pose, and a computer implemented method for providing an EMS input to a wearable fabric. The present invention is directed to the field of human-computer interaction (HCI).

10 Background of invention

Electric muscle stimulation (EMS), also known as functional electric stimulation (FES) or muscle writing, is the generation of muscle activity using electric impulses. The principle is that a current is applied to a target muscle, which then results in an activation and movement of the target muscle. The muscle activity generated will
15 depend on the characteristics of the impulse, as well as the location of the impulse on the target muscle.

EMS is receiving increasing interest due to the potential application for rehabilitation of immobilized body parts and patients, as learning tool and training tool for athletes, and
20 for virtual reality and augmented reality, since EMS can enable mobile force feedback, support pedestrian navigation, and confer object affordances. The EMS system may further be easily portable, such as implemented in a wearable garment as multiple electrodes strategically placed.

25 The current EMS applications are limited by two interlinked problems: (1) EMS is low resolution, achieving only coarse movements, such as the flexing of a hip, knee, ankle, or arm, and (2) EMS requires time consuming, expert calibration.

EMS resolution

30 The challenge surrounding resolution stems from two factors that make targeting desired muscles difficult. Firstly, the anatomy of most gestures, e.g. gestures performed with a muscle or muscle groups in the forearm, is complex, with muscles both tightly packed and layered. Secondly, trans-cutaneous stimulation disperses unpredictably into the underlying tissue and muscle.

35

Higher resolution may be obtained by invasive needle-based stimulation, however this results in reduced comfort and control of muscle fatigue. Higher resolution may also be obtained by multiple skin electrodes placed with a high-density around the target muscle(s), and by uniquely shaped electrodes. Thus, stimulation of more precise movements may be obtained, and simultaneously the range of possible motions may be increased.

EMS calibration

By the term “calibration” is meant the process to determine the positioning of the electrodes on the skin or muscle (spatial calibration), and the tuning of the electric stimulation parameters (signal calibration, including amplitude, pulse width, and frequency), to obtain a target movement or gesture, while minimizing discomfort to the skin of the user. Inherently, EMS must be calibrated individually to each user, since parameters such as muscle size, depth of fat, and skin resistance will vary from person to person. Thus, calibration is typically time-consuming and not applied in real-time, i.e. carried out as a separate step, or as separate iterations, before the EMS can be applied correctly.

The issues with resolution and calibration are further conflicting in nature. Improved stimulation resolution may be obtained by increasing the number of electrodes, e.g. by forming an array or grid of electrodes. However, as the number of electrodes increases, the calibration complexity increases exponentially due to the increased number of variables combinations.

Conventional EMS requires time-consuming, per-user calibration. The calibration involves both *spatial calibration*, correctly positioning the electrodes, and *signal calibration*, tuning stimulation parameters, to target correct muscle depths and minimize discomfort.

A typical calibration process may proceed as follows: the EMS-designer first determines their target gesture and from there identifies the required muscles. They may choose to do this anatomically, such as by using muscle diagrams, or through visual or tactile inspection of arm-surface deformations during muscle contractions (e.g., palpation).

As not all muscles are targetable individually, not all gestures are available to the designer. Thus, the EMS designer engages in a back and forth, trial-and-error led procedure, where electrodes are placed, tested, repositioned, tested, and so on. This is “spatial calibration”. Simultaneously to this process, the designer will be testing a range of signal parameters, varying the pulse-width, frequency and amplitude at each new electrode position, as these parameters can change the resultant movement. This is “signal calibration”.

Once approximate electrode positions and signal parameters are determined, these can then be used as a guide with which to calibrate each individual user. Due to individual differences, including depth of fat, muscle size, skin resistance, etc., the exact electrode locations and signal parameters will vary per user. This process is time-consuming, taking up to five minutes per participant per desired pose or gesture when only positioning a small number of electrodes. If a complex set of gestures is required for the interaction technique, such as the six poses, then the required time for calibration can quickly become impractical, requiring up to 30 minutes of setup prior to every use.

EMS array

Multiple electrodes and higher resolution may be obtained using an EMS array or grid. The electrodes are fixed relatively to each other within the array or grid, and the spatial calibration thus relates to which electrodes in the array to employ or activate.

Based on the calibration, the multiple electrodes may then be selected and coordinated to provide stimulation. Inherently, the available permutations of electrode combinations and thus also the complexity of spatial-calibration, increases exponentially with the number of electrodes comprised in the array.

The potential resolution for an array will depend on the number of electrodes, the shape and coverage degree of the electrodes, as well as the spacing between the electrodes.

EP3184143 [1] discloses a sock comprising an array of skin electrodes, where a subset of electrodes in the array is EMS activated, and where the activated subset electrodes is selected, or calibrated, based on e.g. a simple impedance measurement.

WO 2012/003451 [2] discloses a wearable garment comprising an array of electrodes. The system is a multi-channel, closed-loop FES system, where a first muscle response is generated by a first FES signal and then detected by electromyography (EMG). The detected EMG signal is then applied directly to adjust the second FES signal in real-time, and the process may be repeated in a closed-loop.

Despite the technological advances, for the arrays to become more industrial relevant, there is a need for EMS electrode arrays with higher resolution and faster and real-time calibration.

Summary of invention

The present disclosure provides devices and methods facilitating a higher resolution of muscle activity with EMS, thus enabling finer motor control, and potentially enabling a muscle resolution being suitable for playing a musical instrument such as the piano.

The present disclosure further provides methods and devices configured for faster and real-time calibration of an electrode array for EMS. This is obtained by using electromyography (EMG) to auto-calibrate the EMS array, where the EMG data is further processed to facilitate higher muscle resolution. Optionally, the EMS array is high-density, i.e. has a high density of electrodes, and optionally heuristics or automated procedures are further included to enable faster calibration.

Thus, the present disclosure provides auto-calibration, and real-time calibration and real-time writing of muscle(s) activity or muscle(s) poses. The invention was further seen to provide improved accuracy of a muscle(s) activity, when e.g. replaying a predefined gesture. The invention further provides improved resolution, including finer motor control, e.g. by reading/writing combined agonist and antagonist muscles.

The present disclosure further provides improved resolution for HCI (human-computer-interaction).

A first aspect of the invention relates to a wearable garment fabric for electric muscle stimulation (EMS) comprising:

- an array of electrodes, wherein the electrodes are configured for multi-channel electromyography (EMG) and multi-channel EMS pulses,
- an EMG control system configured for collecting EMG data within the electrode array when the fabric wearer makes a muscle(s) pose, and
- 5 - an EMS control system configured for generating EMS pulses within the electrode array to replay the muscle(s) pose, wherein the EMS pulses are calibrated based on the collected and processed EMG data.

10 A second aspect of the invention relates to a circuit for multiplexing EMG and EMS signals from an array of electrodes, comprising:

- at least one EMG unit,
- at least one EMS unit for controlling EMS amplitude, pulse width and frequency,
- one or more switching boards for switching between electrodes,
- at least one switch board for switching between EMG and EMS mode.

15

A third aspect of the invention relates to a method for calibrating EMS for a muscle(s) pose, comprising the steps of:

- mounting the wearable fabric according to the first aspect on a user,
- providing the target muscle(s) pose,
- 20 - collecting EMG data within the electrode array simultaneously with the muscle(s) pose,
- clustering the EMG data using k-means clustering,
- providing EMS pulses within the electrode array based on the clustered EMG data, whereby the desired muscle(s) pose is obtained.

25

A fourth aspect of the invention relates to a computer implemented method for providing an EMS input to a wearable fabric according to the first aspect of the invention, comprising the steps of:

- collecting EMG data within the electrode array,
- 30 - clustering the EMG data using k-means clustering,
- providing EMS pulses within the electrode array based on the clustered EMG data, whereby an EMS input is obtained.

A fifth aspect of invention relates to a computer system, such as a mobile device, comprising a processor and a memory and being adapted to carry out the method according to the fourth aspect of the invention.

5 **Description of drawings**

The invention will in the following be described in greater detail with reference to the accompanying drawings.

Figure 1A shows an embodiment of the invention, where the garment fabric is a cotton sports compression sleeve worn around the forearm of a user. The fabric comprises an array of 60 skin electrodes sewn into the inner surface of sleeve in a 6 x 10 grid. The grid is also visible on the outside of the sleeve, since the electrodes interface electrically to the outside of the sleeve with metal poppers. The sleeve and the electrodes are connected to a circuit, exemplified as a switching circuitry in Figure 1A, by a ca. 1.5 m of cable. In another embodiment (not shown), the circuit is also wearable, e.g. by mounting the components of the circuit to a surface of a fabric. Figure 1B shows embodiments of muscles poses, or gestures, performed with a muscle or muscle groups placed in the forearm. The gestures are: wrist extension (top image), wrist flexion (second image from top), lift index finger (third image from top), and squeeze fingers (bottom image). The gestures may either be performed by the user while wearing the garment fabric for real-time calibration or the gestures may be generated by EMS following the calibration.

Figure 2 shows a further embodiment of the invention. Figure 2A shows an embodiment of a custom signal switching boards to multiplex EMG and EMS signals between 60 electrodes. Figures 2B-D shows an embodiment of the process of EMG calibration for EMS. The user puts on the sleeve as illustrated in Figure 2B, and as exemplified in Figure 2B, the sleeve may be equipped with a zipper for easy mounting on the forearm. The user then performs a desired, or target, pose, e.g. wrist extension as illustrated in Figure 2C, whilst EMG data is gathered within, or across, the electrode array. Subsequently, an EMS stimulation pattern is calculated from the EMG data, and the pose may be replayed, or written, by EMS as illustrated in Figure 2D. Optionally, the calculated stimulation pattern may be displayed via an on-screen GUI, and the stimulation pattern, and the amplitudes, frequencies and pulse widths, may be

modified. The accuracy of the replayed pose may be evaluated statistically as the number of times the gesture is replayed correctly.

5 Figure 3 shows an embodiment of a circuit or circuitry design. The circuit comprises two EMG units, one EMS unit, and an Arduino unit. The Arduino routes the signal from the EMS device and two EMG devices onto custom signal switching boards. The switching boards route the signals onto any combination of electrodes within the array, e.g. the 60 electrodes sewn into a sleeve.

10 Figure 4 shows embodiments of collected EMG data using a sleeve comprising an array of 10 x 6 electrodes, while the user performs three different example gestures: point index finger (top row), flex wrist down (middle row), and rotate wrist left (bottom row). The row with 10 electrodes extends from the wrist towards the elbow, and patterns for three different users are shown. Different EMG patterns are seen between
15 different gestures as expected, and individual differences for the same gesture between different users are also seen.

The signal strength for each electrode is indicated by grey scale. An embodiment of the EMG electrode reading pattern, or collection of EMG data within or across the
20 electrode array, is illustrated in Figure 4 bottom left, for user 1 and the gesture rotate wrist left. For a designated anode (indicated with red), EMG data is read bipolarly between the anode and six neighbouring electrodes, such as the three closest electrodes, or cathodes, in the two adjacent rows (indicated with green).

25 Figure 5 shows the exemplary gestures used in the test detailed in Example 1. The gestures include: a) wrist flexion, b) wrist extension, c) radial deviation, d) ulnar deviation, e) squeeze fingers, f) lift index finger.

Figure 6 shows the results of the accuracy test detailed in Example 1 in the form of a
30 confusion matrix. 9 repetitions of each of the six exemplary gestures shown in the rows (wrist-up, wrist-down, hand-left, hand-right, index-point, squeeze fingers) were requested (or calibrated), and the resulting produced 54 gestures were characterised. 28 out of 54 gestures were produced correctly, corresponding to an average accuracy of 52%. Especially high accuracy was obtained for wrist-down and hand-right, both
35 achieving 89% replay accuracy (8 out of the 9 requested gestures), and an accuracy of

67% was obtained for the gesture index-point, where 6 out of the 9 requested gestures were accurately produced. Thus, for the best three gestures, an accuracy of 82% was obtained.

5 Figure 7 shows a flow diagram of the reading from and writing to electrode process. The diagram covers the wearer performing a pose, the EMG data being collected and processed into regions of similar amplitude, and the EMS parameters being determined and set.

10 Figure 8 shows the circuitry schematic for an embodiment of a circuit. The circuit comprises signal switching relays (component CPC1218Y) to turn on or off specific electrodes, and shift registers (component SN74HC595N) to guide specific signals to specific electrodes.

15 **Detailed description of the invention**

The present invention surprisingly found that a high-density EMS array may be calibrated using electromyography (EMG), and thereby eliminating the need for expertise in calibration, and reducing the time requirements for calibration, essentially facilitating auto-calibration, or real-time or simultaneous EMS calibration.

20 By the terms "auto-calibration", or "real-time" or "simultaneous" EMS calibration is meant that the EMG calibration step is carried out as a one-step process immediately before or simultaneously with the correct EMS stimulation. This is in contrast to the conventional per-user calibration, where the calibration is an iterative process carried out and completed prior to the correct EMS stimulation.

It was further found that high resolution EMS may be obtained when the electrodes of the array are multi-functional, i.e. active for both EMG (reading) and EMS (writing). Multi-functional electrode arrays were seen to enable an ideal electrode coverage for both signal reading and writing. A gesture, or pose, typically involves the activation of one or more muscles or muscle groups. Thus by the term "muscle(s) pose" is meant the activated one or more muscles required for a given gesture or pose of e.g. a body limb. The multi-functional electrode array of the current invention facilitated that a sufficient region of muscle activity during a human-performed gesture could be both accurately read and written.

30

35

For a given gesture, the read EMG signal across or within the array may be considered as an EMG map. The read EMG map is processed, or calibrated, into an EMS signal or EMS map that can produce or replay the same given gesture. The EMS map required to produce or replay the same given gesture may be the same or different from the EMG map read.

Figures 1-2 show an embodiment of the invention, where the electrode array is embedded in a wearable garment in the form of a compression sleeve worn around the forearm of a user. The multiplexing between electrodes within the array, and the EMG and EMS signals are obtained by a circuit connected to the sleeve by cables, as illustrated in in Figures 1A and 2A.

An embodiment of the process of auto-calibrating the EMS map is illustrated in Figures 1-2. The user applies the electrode array by putting on the sleeve as illustrated in Figure 2B, and as exemplified in Figure 2B, the sleeve may be equipped with a zipper for easy mounting on the forearm. The user then performs a desired, or target, pose, e.g. wrist extension as illustrated in Figure 2C, whilst EMG data is gathered or collected across, or within, all electrodes of the array. Subsequently, an EMS stimulation pattern is calculated from the EMG data, where the system identifies the electrode configuration required to perform this gesture with EMS. The system thus provides a mapping for EMS stimulation of the same gesture, and the pose may be replayed, or written, by EMS as illustrated in Figure 2D.

The same auto-calibration process may be carried out for any target gesture involving any muscle poses. Figure 1B illustrates other examples of gestures or muscles poses performed with a muscle or muscle groups placed in the forearm. The gestures are: wrist extension (top image), wrist flexion (second image from top), lift index finger (third image from top), and squeeze fingers (bottom image).

Optionally, the calculated stimulation pattern may be displayed via an on-screen GUI, and the stimulation pattern, and the amplitudes, frequencies and pulse widths, may be modified as indicated in Figure 2D.

The accuracy of the replayed pose may be evaluated statistically as the number of times the gesture is replayed correctly.

Array

5 The electrode array configuration, including electrode coverage, number, size, position pattern, and spacing, determines the potential resolution, the degree of trans-cutaneous dispersion, and the calibration complexity. Different electrode array configurations may easily be obtained by incorporating the electrodes into a garment fabric.

10

As an example, Figure 1A shows an embodiment of the invention, where an array of 60 skin electrodes are sewn into the inner surface of sleeve, or a garment fabric that is a cotton sports compression sleeve worn around the forearm of a user, covering the wrist to the elbow. The array designed as a sleeve further support easy application and removal across a wide range of arm sizes. The array designed as a fabric garment is further configured to cover one or more muscle(s) group. The more muscle groups that are covered, the more possible gestures can be calibrated. A fabric system spanning the entirety of the forearm as illustrated in Figure 1A, covers several muscle groups and has the potential for many gestures to be calibrated.

20

In an embodiment of the invention, the array of electrodes is incorporated in a wearable garment fabric, such as a sleeve, configured to be worn around the forearm of a user. In an embodiment of the invention, the fabric is configured to cover one or more muscle(s) groups. In a further embodiment, the fabric is configured as a sleeve to cover the entire forearm.

25

The array of the current invention advantageously comprises electrodes that are configured for multi-channel electromyography (EMS) and multi-channel electric muscle stimulation (EMS). Thus, the electrodes are configured for both reading and writing a muscle or muscle(s) group, and the reading and writing may be obtained from any individual channel and simultaneously from one more channels. By the term "channel" is meant any electrode, or across any electrode pair, within the array.

30

The current array may obtain an advantageous high resolution by combining a high electrode surface coverage degree, with a sufficient distance between the electrodes,

35

which may minimize the individual trans-cutaneous dispersion over the underlying tissue and muscle. The high electrode coverage degree and multi-channel potential are in contrast to conventional arrays based on simple 1:1 (anode:cathode) reading and writing, where each electrode may be pre-designated and only used for either reading or writing, and where each electrode is pre-designated and fixed as either anode and cathode.

The EMG reading and EMS writing resolution will depend on the spatial coverage of the electrodes. Thus a potentially higher resolution is obtainable for multi-functional arrays, where the same electrodes are used for both sensing and stimulation, since an increased spatial coverage of the array is possible.

In an embodiment of the invention, the wearable garment fabric for electric muscle stimulation (EMS) comprises:

- an array of electrodes, wherein the electrodes are configured for multi-channel electromyography (EMG) and multi-channel EMS pulses,
- an EMG control system configured for collecting EMG data within the electrode array when the fabric wearer makes a muscle(s) pose, and
- an EMS control system configured for generating EMS pulses within the electrode array to replay the muscle(s) pose, wherein the EMS pulses are calibrated based on the collected and processed EMG data.

The exemplified fabric in Figure 1A comprises an array of 60 skin electrodes sewn into the inner surface of sleeve in a 6 x 10 grid. The grid is also visible on the outside of the sleeve, since the electrodes interface electrically to the outside of the sleeve with metal poppers.

The sleeve and the electrodes are connected to a control circuit, exemplified as a switching circuitry in Figure 1A, by a ca. 1.5 m of cable. This supports a wide range of motion when wearing the sleeve. However, the sleeve and circuit may also be fully wearable, e.g. achieving miniaturization through surface mount components, which would enable a more independent use, e.g. when using the array on a tennis court, or when using the array when moving around the house, whilst cooking.

In a (not shown) embodiment of the invention, the control circuit may be wearable, e.g. by mounting the components of the circuit to a surface of a wearable fabric.

Advantageously, the electrodes of the array are skin electrodes, since this facilitates
5 easy mounting and dismounting of the array and fabric.

In an embodiment of the invention, the electrodes are skin electrodes.

The electrode array configuration, including electrode coverage, number, size, position
10 pattern, and spacing (i.e. inter-electrode spacing), determines the potential resolution and the degree of trans-cutaneous dispersion. By the term "electrode size" is meant the size of the contact surface area with the user, e.g. the skin of the user.

The electrode array configuration further influences on the user's comfort during
15 application. For example, an electrode array comprising few electrodes, or electrodes with a small size or with a small inter-electrode spacing, may result in a burning sensation on the skin of the user due to the current density. However, a higher number of electrodes, bigger sizes and spacing increases the complexity of resolution and trans-cutaneous dispersion.

Advantageous resolution in combination with a reduced transcutaneous dispersion and
20 discomfort for the user, is observed for a fabric comprising an electrode array covering a high degree of the fabric, and inherently a high degree of the limb or muscle(s) groups to be covered by the fabric, and where the number of electrodes are above 10, and/or where the electrodes are placed in the pattern of rows, and/or the size of each
25 electrode is between 1 to 10 cm², and/or the distance between neighbouring electrodes is between 5-30 mm.

In an embodiment of the invention, the contact surface area of the electrodes cover the
30 fabric with a coverage degree between 10 to 99%, more preferably between 50 to 90%, and most preferably between 60 to 80%.

In an embodiment of the invention, the array of electrodes comprises above 10
electrodes, more preferably between 20 to 80 electrodes, such as 60 electrodes, and
35 most preferably above 100 electrodes.

In an embodiment of the invention, the arrays of electrodes are placed in one or more rows thereby forming a grid, such as six rows where each row comprises ten electrodes.

5

Advantageous resolution may be obtained by further decreasing the individual electrode sizes. In an embodiment of the invention, the contact surface area of each electrode is between 0.4 to 10 cm², more preferably between 0.5 to 5 cm², and most preferably is between 0.8 to 4 cm², such as 1 or 3 cm².

10

In an embodiment of the invention, the distance between neighbouring electrodes is between 5 to 30 mm, more preferably between 10 to 20 mm, and most preferably between 10 to 15 mm.

15

The resolution and muscle selectivity, and degree of trans-cutaneous dispersion and discomfort, will also be affected by the contact degree between the electrode surface and the surface of the user, e.g. the surface skin of the user. Poor contact may for example be due to poor electrode adhesion along the edges, and the decreased contact will result in an effectively smaller contact surface and uneven current distribution. Thus, advantageously the electrodes are made of materials that are easily adhered to the skin, and which have shapes and sizes facilitating contact along the edges.

20

25

Sufficient contact degree was obtained in the exemplified high-density electrode sleeve of Figures 1-2 based on a cotton sports compression sleeve, where sixty ca. 2×1.5 cm electrodes were sewn into the sleeve in a 6×10 grid. The electrodes were cut from conductive fabric and interfaced to the outside of the sleeve with metal poppers.

30

In an embodiment of the invention, the electrodes comprise a conductive fabric.

Advantageous resolution and contact degree between the electrode surface and the surface of the user may be obtained with certain shapes of electrodes, and/or if the electrodes are protruding in e.g. a stud like manner.

In an embodiment of the invention, the shapes of the electrodes are selected from the group of: rectangular, circular, oval, squared shaped, and stud shaped, and most preferably is rectangular shaped or stud shaped.

- 5 In an embodiment of the invention, the size of the electrodes correspond to a rectangular electrode with a first length between 10 to 30 mm, such as 20 mm, and a second length between 10 to 30 mm, such as 15 mm.

- 10 The contact degree between user and electrode surface may further be improved by the application of a conductive gel. Thus, the gel may serve to distribute the stimulation across a wider area, decrease between-/inter-electrode effects, and improve the resolution.

- 15 For example, a layer of electrode hydrogel, such as Axelgaard's AG635 'Sensing' Hydrogel, ensures a good or complete connection between the conductive fabric and the skin. The gel may be cut into per-electrode pieces, and applied to each electrode individually. Alternatively, one large sheet of electrode gel can be applied.

- 20 In an embodiment of the invention, the fabric further comprises an electric gel, such as an electrode hydrogel. In a further embodiment, the electric gel is configured to be applied to each electrode individually or applied as a single unit.

- 25 As shown in Figure 2B, for ease of application a zip may be added to the side of the sleeve. Thus, the sleeve can be put on and removed by the wearer. Advantageously, the design of the sleeve is such that the zip is worn down the center of the inner forearm, as the wearer can hold the top of the zip with their wearing-hand, while pulling the zipper with their other hand.

- 30 In addition to easy application, the zipper supports a one-time calibration process. By the term "one-time calibration" is meant that the fabric can be mounted and dismounted any number of times for a given user, and be continuously calibrated without the need of re-calibration every time the fabric is mounted. This is facilitated by the configuration of the electrodes, particularly the size of the electrodes and the multiple-electrode patterns, which enables that the re-applied array of electrodes may be closely aligned
35 with their initially calibrated position.

The one-time calibration process may be further improved by further tailored designs, which indicate the positioning of certain muscle groups and/or body parts, such as the use of a “thumb loop” and/or clear “elbow patch”.

5

In an embodiment of the invention, the fabric further comprises a zipper. In a further embodiment, the fabric comprises a thumb loop and/or elbow patch.

Advantageously the array and fabric are integrated such that high flexibility during mounting, use, and maintenance is obtained. In an embodiment of the invention, this may be obtained by wearable electronics, e.g. by wiring integrated into the wearable, with small electronic control box mounted onto exterior of fabric. In a further embodiment, the fabric is configured as a stretchable compression garment form factor (i.e. without zip) that can be simply pulled on. In a further embodiment, the fabric is configured to have multiple form factors, e.g. both sleeves and leg tights form factors. In a further embodiment, the array and fabric are configured to be machine washable.

10
15

EMG control system

The combination of the multi-functional EMG/EMS array of the current invention and EMG mapping across the electrode array for a posed gesture, result in an advantageous resolution and spatial auto-calibration of the EMS array, where manual positioning and repositioning of electrodes is avoided.

20

The EMG reading or calibration is based on a “per-pose” approach, rather than “per-muscle”. This means that users can apply the electrode array without the requirement for precise alignment and without the need for in-depth physiological knowledge. In addition to the easy and accessible use, the array may be both rotation and position invariant, and the array may be configured to be one-time calibrated.

25

The potential complexity of the EMG reading (or EMG mapping or calibration) and EMS writing (or EMS mapping) increases exponentially with the number of electrodes within an array.

30

A conventional array applies pair-wise calibration, where the electrodes are pre-designated and fixed as anode and cathode. Thus, the complexity or number of

35

combinations are eliminated, since the reading and writing occurs as a simple pre-fixed 1:1 (anode:cathode).

5 However, for the array of the current invention, any electrode may act as anode or cathode, and thus any electrode acting as anode may act as anode for a multiple of cathode electrodes.

10 Thus, any combination of p:q electrodes (where $p, q \geq 1$) are possible for the current array. This means that a complete electrode mapping (reading or writing) for an array where n is the number of electrodes, includes a total of $(3^n - 2^{n+1} + 2)$ configurations or combinations. For example, for an array comprising 60 electrodes involves a complete reading between 306 unique electrode combinations.

15 The number of electrode combinations described above is based on bipolar EMG configuration, i.e. that the EMG data are collected bipolarly between two electrodes, an anode and a cathode. Alternatively, EMG data may be gathered from an individual electrode, i.e. monopolar configuration. Thus, in a monopolar configuration, a complete EMG mapping involves only a reading for each n electrode. However, monopolar EMG requires additional data processing, and monopolar EMG may produce improved
20 accuracy compared to bipolar configuration. Depending on the requirements for accuracy and calibration time, monopolar or bipolar EMG configurations may be preferred. Both bipolar and monopolar EMG mapping may involve a reference electrode.

25 In an embodiment of the invention, the EMG control system is configured to collect the EMG data across, or within, the electrode array in a monopolar manner.

In another embodiment of the invention, the EMG control system is configured to collect the EMG data across, or within, the electrode array in a bipolar manner.

30

Bipolar EMG mapping

High resolution, accurate reading, and fast EMG mapping may be obtained using bipolar EMG configuration. Thus, bipolar EMG is advantageously used to read muscle action potentials during muscle actuation, such as while performing and/or maintaining
35 a gesture.

From a physiological point of view, the optimal configuration for the EMG electrodes may be above and below the center of the muscle and then downwards along the muscle fiber, e.g. placed 10-30mm apart. However, not all muscle fibers tend downwards, for example pennate muscles, such as the flexor carpi ulnaris in the forearm. Thus, more accurate EMG reading may be obtained by reading across a cluster of neighboring bipolar electrode pairs, and not just directly down the muscle fiber or sleeve.

Figure 4 shows an embodiment of how the EMG reading may be obtained across a cluster of neighboring electrode pairs.

Figure 4 shows embodiments of collected EMG data using a sleeve comprising an array of 10 x 6 electrodes, while the user performs three different example gestures: point index finger (top row), flex wrist down (middle row), and rotate wrist left (bottom row). The row with 10 electrodes extends from the wrist towards the elbow, and patterns for three different users are shown. Different EMG patterns are seen between different gestures as expected, and individual differences for the same gesture between different users are also seen.

The signal strength for each electrode is indicated by blue/grey scale. An embodiment of the EMG electrode reading pattern is illustrated in Figure 4 bottom left, for user 1 and the gesture rotate wrist left. For a designated anode (indicated with red), EMG data is read bipolarly between the anode and six neighbouring electrodes, such as the three closest electrodes, or cathodes, in the two adjacent rows (indicated with green).

Thus, readings are taken between each electrode and the 3 closest electrodes in the next two rows for a total of 306 unique pairings. Advantageously, the reading starts from the top of the sleeve, nearest the shoulder, and continues downwards towards the wrist, following the muscular anatomy of the forearm. Reference electrodes may be placed on the biceps brachii.

The bipolar EMG reading illustrated in Figure 4 was observed to result in high resolution, accurate reading, and fast EMG mapping.

In an embodiment of the invention, the EMG control system is configured to collect bipolar EMG readings between each electrode and six neighbouring electrodes. In a further embodiment, the EMG control system is configured to collect bipolar EMG readings between each electrode and the three closest electrodes in two adjacent rows. In a further embodiment, the EMG control system is configured to collect bipolar EMG readings between each electrode assigned as anode and six neighbouring cathodes.

The EMG control system may be in the form of a circuit, where the circuitry uses relays to select between different electrode pairs.

The process of switching EMG signals between electrodes may add a spike to the EMG signal. To avoid the noise, for example each EMG pair may be read for 220 ms and only the data from the last 20ms is used.

To improve the speed of the calibration process, switching EMG signals between electrodes may be obtained by more than one EMG unit. For example two EMG devices may be used concurrently, where a full reading cycle may take ca. 45seconds (for 306 unique electrode pairs in a 60 electrode array).

During reading or calibration, where the EMG electrode switching cycle occurs, the user must actively hold the desired gesture or target pose, i.e. maintain the muscle tension. This results in the classification of poses, not dynamic gestures. Thus, advantageously the reading time is shortened by combinations of (a) customized EMG hardware allowing signal rectification in code not hardware, (b) using more EMG channels simultaneously, however, this introduces additional hardware complexity, and/or (c) using feature vector patterns from dynamic gesture data.

To improve the accuracy of the reading, the EMG data may be corrected by a baseline pose. This may be obtained if the user puts on the sleeve and EMG data for the initial "rest" pose is read as a baseline from which to normalize future poses. The normalization helps mitigate the effect of muscle activity involved in the rest pose. The user then performs and holds a desired pose whilst EMG data is collected for the calibration.

To improve the accuracy of the reading, and the resolution of the calibration for the EMS, several data are collected for each electrode pairing, and the data may be further processed. For example, the root mean square (RMSQ), standard deviation and signal peak maximum may be calculated for each electrode pairing. These values may be standardized against the corresponding values from the rest pose.

Advantageously, the electrodes in each pair is labeled respectively anode and cathode, and then sorted into 3 groups using k-means clustering. The three clusters are 1) inactive, 2) low potential, and 3) high potential. The clustering may be based on the use of two stimulation channels. Both the anode and cathode electrodes are added to the calculated cluster.

As individual electrodes occur in multiple pairings, for example each anode is paired with six cathodes, as illustrated in Figure 4, it is possible that any one electrode can be placed in multiple clusters (inactive, low, or high potential). In this case, the electrode in the highest cluster is prioritized (where high potential > low potential > inactive). Within each cluster, the electrode pairs are sorted by RMSQ magnitude. Electrodes are finally selected as anode, cathode, or 'off' based on their highest cluster and highest magnitude pairing. This electrode assignment is subsequently used for EMS.

An amplitude ratio between the stimulation channels may be automatically calculated from the average RMSQ of each cluster. This ratio is balanced with the number of electrodes in each cluster as the current per electrode decreases with increasing electrode count.

Once calculated, the stimulation pattern may be presented to the user through a GUI, and the system may automatically maintain the amplitude ratio between the EMS channels. Optionally the user can modify the amplitude, pulse width and frequency of the pattern either through keyboard shortcuts or with the mouse.

In an embodiment of the invention, the EMG control system is configured to cluster each electrode pair using k-means clustering.

The method of the current embodiment includes reading between each electrode and its six neighboring electrodes. This is in order to improve reading accuracy along

muscles that do not tend directly down the arm (pennate muscles, for example). This adds a complexity to our mapping procedure, since at any given electrode location, we do not know which electrode pair to favor.

- 5 While we assume that electrodes directly down the muscle body will provide the highest readings, this is a potential source for noise and error. Since the muscle structure under the electrodes cannot be determined, it may be beneficial to move from a bipolar EMG configuration to a monopolar configuration (gathering EMG data from individual electrodes). This has recently been shown to offer increased accuracy over a
10 bipolar approach when processing data from the 5th principle component.

EMS mapping

- The electrode array of the current invention is a multi-functional EMG reading and EMS writing system. Thus, the same complex patterns of electrodes, or electrode
15 combinations, may be used for EMS as for EMG. Thus, for EMS the number of electrode configurations is also $p:q$ electrode configurations, where $p, q \geq 1$. The EMS is also multi-channel and multi-amplitude, thus forming electrodes of arbitrary shape and size.

- 20 Multi-channel EMS enables primary and secondary stimulation patterns, where the primary actuation is controlled by one channel and causes the principle motion, with a second channel building upon or subtracting from this motion. For example, the primary electrodes may pull the hand up at the wrist, whilst the secondary electrodes provide small alterations to finger positions. Alternatively, agonist (primary) and antagonist
25 (counter) muscles can be targeted separately. Combining electrodes also serves to distribute the stimulation signal across a larger surface area. As a result of this, the user may choose to increase the EMS amplitude beyond that typical if using a pairwise configuration.

- 30 According to the current invention, the multi-channel and multi-amplitude EMS map for a posed gesture is advantageously obtained based on the collected and processed EMG map across the same electrode array.

- In an embodiment of the invention, the EMS control system is configured to generate
35 EMS pulses based on the clustered EMG data.

The EMS map required to produce or replay the same given gesture may be the same or different from the EMG map read. In addition the EMS map required to produce a given gesture over a certain amount of time may vary. For example, when holding a pose, co-activation can cause EMG potentials across the two muscle compartments. However, where agonist muscle potentials increase over time, antagonist muscles do not. Thus, the agonist-antagonist behavior may include changes in certain electrodes over time.

10 In an embodiment of the invention, the EMS control system is configured to generate EMS pulses that are multi-channel, multi-amplitude, and/or variable over time.

Based on the EMG calibration, an accurate and high resolution EMS map for a gesture or muscle(s) pose may be obtained.

15

In an embodiment of the invention, the method for calibrating EMS for a muscle(s) pose, comprises the steps of:

- mounting the wearable fabric comprising the array of electrodes according to the invention,
- 20 - providing the target muscle(s) pose,
- collecting EMG data across, or within, the electrode array simultaneously with the muscle(s) pose,
- clustering the EMG data using k-means clustering,
- providing EMS pulses across, or within, the electrode array based on the clustered
- 25 EMG data, whereby the desired muscle(s) pose is obtained.

Advantageously, the method for calibrating EMS is a computer implemented method, adapted to provide an EMS input to a wearable fabric according to the invention.

30 An embodiment of the invention comprises, a computer implemented method for providing an EMS input to a wearable fabric according to the invention, comprising the steps of:

- collecting EMG data across, or within, the electrode array,
- clustering the EMG data using k-means clustering,

- providing EMS pulses across, or within, the electrode array based on the clustered EMG data, whereby an EMS input is obtained.

Target muscle(s) pose or routine

5 The provided target pose may be provided as a fixed pose (i.e. the person has to hold the fixed pose), or as dynamic poses. Thus, e.g. both semaphore, and American Sign Language, for example, where the way in which you move into and out of poses is important, may be supported by the current system. In an embodiment of the invention, the target gesture, or muscle(s) pose, is a fixed pose or a dynamic pose.

10

An example of a dynamic pose that may be provided for calibration includes: the user puts the sleeve on, perform a known gesture 'routine' (i.e. swirl your wrist and wriggle your fingers). Collecting EMG data during that routine will then inform the system of muscle locations that then enable the electrode configuration for any gesture to be
15 calculated for EMS mapping.

15

Another embodiment of further calibrating a dynamic target gestures or routines may be applied in sports. For example the user does a motion (for example, swings a baseball bat), during which EMG is read. After the motion, the user rates the swing
20 from 1-10. They do this e.g. 5 times. On their sixth swing, the system automatically adjusts their movement (using EMS) towards their highest ranked previous movement or dynamic target gesture.

20

To further simplify the process of providing a target gesture and the calibration, several
25 gestures may be calibrated based on a reference person. Thus, the system may be configured to be 'cross person' calibrated for several predetermined stimulation gestures. For example, a set of 10 gestures may be predetermined and calibrate for the reference person. Based on just one of the gestures supplied by a subsequent user, and the associated calibration process, the remaining nine predetermined
30 gestures may be automatically calibrated for the subsequent user.

30

To further simplify the process of providing a target gesture and the calibration, the step of gathering EMG data may be avoided, and the EMS electrode configurations for stimulating specific gestures may be based on machine learning, such as neural
35 network.

35

Circuit

Advantageously, the EMG control system and EMS control system are incorporated in the same control system. This may further facilitate faster and real-time application of the system, for example by enabling simultaneous, overlapping, or immediate successive EMG and EMS processing steps. For example EMG readings may be obtained inbetween EMS pulses.

Improved real-time application of the system may be obtained by performing EMG readings between individual pulses of EMS. The residual surface charge is drained, allowing EMG data to be collected. In another embodiment of the invention, the EMG electrodes are read between individual pulses of stimulation.

In an embodiment of the invention, the EMG and EMS control systems are configured to operate simultaneously, optionally by performing EMG readings between EMS pulses.

Embodiments of a EMG and/or EMS control system is shown in Figures 1A and 2A. A schematic embodiment of the control system is shown in Figure 3. Figure 3 shows an embodied circuit or circuitry design. The circuit comprises two EMG units, one EMS unit, and an Arduino unit. The Arduino routes the signal from the EMS device and two EMG devices onto custom signal switching boards. The switching boards route the signals onto any combination of electrodes within the array, e.g. the 60 electrodes sewn into a sleeve.

The circuit enables multiplexing both EMG and EMS signals across the electrodes of the array or sleeve.

In an embodiment of the invention, the circuit for multiplexing EMG and EMS signals from an array of electrodes, comprises:

- at least one EMG unit,
- at least one EMS unit for controlling EMS amplitude, pulse width and frequency,
- one or more switching boards for switching between electrodes,
- at least one switch board for switching between EMG and EMS mode.

The number of components for the circuit is advantageously kept to a minimum to facilitate portability and miniaturization of the circuit.

In a further embodiment, the circuit comprises two EMG units and one EMS unit.

5

A high number of EMG- and EMS units are advantageous for further improving real-time application and reading/writing resolution. Thus, in a further embodiment of the invention, the circuit comprises between 2-100 EMG units, and/or 2-100 EMS units, more preferably between 10-80 EMG units and 10-80 EMS units, such as 60 EMG units and 60 EMS units.

10

In a further embodiment, the circuit is configured to be used as the EMG and/or EMS control system for the fabric or array of the current invention.

15

Optionally, the EMG and EMS units are off-the shelf units, such as EMG devices from Backyard Brains, Muscle Spiker shields, and an EMS device from Med-Fit 1, dual channel Tens machine. This EMS device may provide control of signal amplitude, pulse width and frequency. The parameters may be controlled through 2 digital potentiometers (DS1803-050, 2 channel, 256-step, 50k Ω). The amplitude may also be manually controlled through two 20k Ω potentiometers, thus having 102-steps of amplitude resolution control.

20

Optionally, the circuit includes custom PCBs to control the signal-electrode switching. Each signal switching board routes the signals, in any combination, to 6 electrode connectors (for one row of the embodied sleeve). The signals are routed through an array of 24 solid-state relays (2 per channel per electrode, CPC1218Y1). The relays are controlled through 3 chained 8-bit shift registers (SN74HC595N). We use 10 signal switching boards in total (for the embodied 10x6 electrode sleeve), stacked through connecting headers into a tower (240 relays in total). Additional relays switch the inputs to the signal switching boards between EMG and EMS, and power on/off the EMG and EMS devices as needed, to prevent any potential electrical damage. NO relays (normally open) ensure no stimulation signal connection to the wearer, should an error occur or the switching board power fail.

25

30

Optionally, the solid state relays are rated to 60V. While the EMS device provides 40V maximum at 500 Ohm, the current driven signal can exceed 60V at skin-level resistance. This high-level voltage only occurs in brief voltage spikes. Advantageously a relay with a higher maximum voltage may be applied for safety, such as the
5 CPC1215.

Optionally, the custom signal switching boards and circuitry are driven through an Arduino Mega (requiring 56 digital pins and 2 analog pins). An additional 5V power supply is used to support the current requirements of the switching boards. The
10 Arduino may be interfaced with Python, to provide a GUI for control.

Example 1 shows an embodiment of the schematics for a control source code.

Example 4 shows an embodiment of a circuit and the fabrication of the circuit.
15

In an embodiment of the invention, the circuit is configured to perform the methods, according to the third and fourth aspects of the invention. In particular, the circuit is configured to perform the parts of the methods comprising the steps of:

- collecting EMG data within the electrode array,
- 20 - clustering the EMG data using k-means clustering,
- providing EMS pulses within the electrode array based on the clustered EMG data, whereby an EMS input is obtained.

Preferably, the circuit is configured to perform the parts of the methods comprising the steps of:
25

- collecting EMG data within the electrode array simultaneously with the muscle(s) pose,
- clustering the EMG data using k-means clustering,
- providing EMS pulses within the electrode array based on the clustered EMG data,
30 whereby the desired muscle(s) pose is obtained.

Advantageously, the circuit is configured to implement the steps of the methods mentioned above. In a further embodiment, said steps may be performed by a separately connected part of the circuit, such as a separate computer program, a
35 plugin to an existing service running on a device or online, or a mobile device

comprising a processor and memory adapted to perform the steps, such as an application for smartphones or as software running on a PC or laptop. Thus, the steps are configured as computer implemented steps.

5 In an embodiment of the invention, the following steps of the methods:

- collecting EMG data within the electrode array simultaneously with the muscle(s) pose,
 - clustering the EMG data using k-means clustering,
 - providing EMS pulses within the electrode array based on the clustered EMG data,
- 10 whereby the desired muscle(s) pose is obtained.

are performed by the circuit according to the invention, or by a separately connected computing part of the circuit thus being configured as computer implemented steps.

15 Preferably, the separately connected part of the circuit is a mobile device comprising a processor and a memory. An aspect of the invention, relates to a mobile device comprising a processor and a memory and being adapted to perform the methods according to the invention, particularly the steps of:

- collecting EMG data within the electrode array simultaneously with the muscle(s) pose,
- 20 - clustering the EMG data using k-means clustering,
- providing EMS pulses within the electrode array based on the clustered EMG data, whereby the desired muscle(s) pose is obtained.

25 In an embodiment of the invention, the circuit is configured to be used as an EMG and/or EMS control system.

In a further embodiment, the circuit is configured to carry out the method according to the fourth aspect of the invention.

30 Advantageously, the EMS pulses may be evaluated by the user, and the user may provide input to the system, such as rating the EMS pulses.

35 In an embodiment of the invention, the circuit further comprises a user interface, such as a GUI (graphical user interface) configured for receiving input for modifying the EMS pulses.

In an embodiment of the invention, the system includes a computer system, such as a mobile device, comprising a processor and a memory and being adapted to carry out the method according to the fourth aspect of the invention.

5

Applications

The current invention may be used for any EMS application. The system of the present invention is particularly suitable for being portable and for being integrated into a wearable garment. The applications include rehabilitation of immobilized body parts and patients, as learning tool and training tool for athletes and for personal activities, and for virtual reality and augmented reality.

10

The invention may be applied to any domain including performing any uniform, repetitive task.

15

For example, the wearable fabric sensor may be embodied in a sleeve form. In the first instance, the wearer must perform the task themselves. Having learned the muscle patterns for the activity, the sleeve can subsequently cause the wearer to continue to perform the task without their express concentration. For example, you do only the first stir of your cake mix, before the sleeve takes over and makes you stir whilst you concentrate on something else.

20

The invention is especially well-suited to sports clothing. For example, the system may be incorporated into any sports compression clothing, including shirts, shorts, full leg tights, socks, sleeves, etc. With a different form factor, the same technique as described for stirring a cake mix may be applied to golf. For example, the user may perform 5 manual golf swings and rate each swing. During any subsequent swing, the fabric sensor can monitor the muscle recruitment and correct the movement towards an optimal swing.

25

30

This same concept can be applied across a breadth of sports or other physical tasks. The same technique also allows us to monitor muscle usage during performance. For example, during endurance running, a person's muscle usage slowly weakens as the person become tired. However, a person's ability to use muscle degrades faster than the actual muscles are capable of. The system of the current invention enables to

monitor muscle use in real time and provide a performance boost to keep athletes performing harder for longer.

Thus, the system of the current invention may be applied in a wide range of sports applications. These covers the endurance athletics (for using stimulation during prolonged performance in sports such as running, tennis, cycling), the skill-based sports (where performance of specific actions can be taught and improved, such as pitching in baseball, golf swings), and the resistance sports (where maintaining performance and core muscle recruitment is critical).

Examples

The invention is further described by the examples provided below.

Example 1: Method of using EMG to auto-calibrate a high-density EMS array

In an embodiment of the invention, the EMS calibration was based on EMG data gathered from the high-density electrode array. A flow diagram of the process is shown in Figure 7.

Example 2: Proof-of-concept by auto-calibrating a sixty electrode EMS array with EMG

An array comprising 60 electrodes was used for spatial calibrating EMS with EMG. The calibration involved the multi-electrode patterns for EMS, stimulating between any number of anodes and cathodes with two signal sources.

The EMG based auto-calibration of an electrode array was focused on gestures typically used in the HCI EMS literature.

In our study, we achieve an average of 52% replay accuracy over six gestures, with 82% calibration accuracy on average across our best three gestures. Our most accurate gestures include our most complex gesture; the accurate control of the index finger separately from the other fingers. Overall, we achieve 67% correct identification of target muscle compartments.

Procedure

Nine participants put on the electrode array and performed six gestures previously used in the EMS literature, plus an additional rest gesture for EMG signal base-lining.

These gestures include: wrist flexion (wrist-down), wrist extension (wrist-up), radial deviation (hand rotation towards the thumb, hand-left), ulnar deviation (hand rotation towards the little finger, hand-right), squeeze-fingers, and lift index finger. The gestures are also shown in Figure 5. The order of the gestures was counterbalanced across participants.

Participants were standing during the study and wore the sleeve on their dominant forearm. The participants were instructed to hold their hand over a table in front of them, with their elbow bent at ~90 degrees. While this may introduce some constant muscle tension, the effects of this would be removed by the normalization step in the EMG reading process.

Participants advanced through the study with a wireless keyboard and mouse. The laptop running the stimulation hardware was kept out of reach, preventing any common ground concerns. On-screen instructions guided the participants through the study. Initially, they were asked to manually perform the gestures, during which EMG data was gathered. Upon completing the manual performance and data collection part of the study, the participants moved on to the pose-replay portion of the study.

In a randomized order, the EMS stimulation pattern for each gesture was computed from the EMG data. Once the stimulation pattern was calculated, it was displayed to the participants in an on-screen GUI. The participants were then free to explore the amplitude, frequency and pulse width of the stimulation using the keyboard.

Initial frequency (55Hz) and pulse width (200 μ s) values were configured. The use of the keyboard allowed fine-grained control of each parameter and provided a quick method to disable the stimulation (by pressing the spacebar). The participants were free to spend as long as they wished exploring the parameters.

During exploration of the stimulation pattern, the participants' wrist, back of hand, and fingers were tracked with an OptiTrack motion tracking camera setup (8 Prime13 cameras, 240fps). Data was captured at the end of every complete line of reading (EMG), and after every 5th step of stimulation amplitude increase (EMS). This resulted in 18 frames of data per pose during the reading phase, and 24 frames per pose (on average) during the writing phase. The captured data was automatically inspected after

each participant completed the study. The motion tracking data was used to calculate orientation and position changes of the back of the hand and the individual fingers during poses (manual and stimulated).

5 The target gestures were grouped into pairs based on shared muscle compartments: wrist-up and wrist-down, hand-left and hand-right, squeeze-fingers and index-point. For example, the extensor carpi ulnaris (on the top of the forearm), among other muscles, contracts to extend the wrist. In this case, it is an agonist muscle. The antagonist muscles, such as the flexor carpi ulnaris (on the bottom of the forearm), relax to enable
10 wrist extension. When flexing the wrist, however, the role of these muscles is reversed. When holding a pose, co-activation of both agonist and antagonist muscles can occur , producing discernible signals for our EMG devices. Therefore, we pair gestures in our analysis to explore the correct identification of active muscle compartments.

15 Results

The participants performed 54 gestures in total. The results are summarised in Figure 6 in the form of a confusion matrix. Nine repetitions of each of the six exemplary gestures shown in the rows (wrist-up, wrist-down, hand-left, hand-right, index-point, squeeze fingers) were requested (or calibrated), and the resulting produced 54 gestures were
20 characterised. 28 out of 54 gestures were produced correctly, corresponding to an average accuracy of 52%. Especially high accuracy was obtained for wrist-down and hand-right, both achieving 89% replay accuracy (8 out of the 9 requested gestures), and an accuracy of 67% was obtained for the gesture index-point, where 6 out of the 9 requested gestures were accurately produced. Thus, for the best three gestures, an
25 accuracy of 82% was obtained.

Wrist-down and Hand-right were the most accurately reproduced poses, with 89% accuracy. This means that, at some time during exploration of the EMS pattern, the back of hand and/or fingers were stimulated to move in the target direction. For both of
30 these poses, the error case moved in the direction of the target's opposing movement, Wrist-up and Hand-left, respectively.

Index-Point was the next most accurately reproduced, with 67% accuracy. The index-point errors all resulted in a Wrist-Up pose.

Hand-left was the least accurate pose, with only 11% accuracy. The majority of the Hand-Left stimulation patterns resulted in a Wrist-Down pose.

Squeeze-Fingers was the second least accurate, with 33% accuracy.

5

On average, 28 (52%) of the gestures were replayed correctly. 8 (15%) of the EMS gestures moved in the direction of the target's pair (i.e. favoring the antagonist muscles). For example, four instances of the wrist-up gesture moved in the hand-down direction. 15 (28%) of the gestures moved in a wrong axis, and 3 (6%) instances

10 resulted in no movement at all.

Discussion

EMS in HCI is currently restricted by two challenges. First, it is low resolution, supporting only coarse movements across a limited range of gestures and preventing opportunities for complex interaction techniques. Second, it requires expert calibration to determine correct electrode positioning and signal parameters. High density electrode arrays can both increase stimulation resolution, better supporting finer movements, and improve comfort and reduce fatigue. But they are complex to calibrate and are yet to be adopted in HCI. We explore EMG as a method of auto-calibrating EMS arrays. We explored auto-calibration of complex stimulation patterns in EMS arrays. Through this exploration, we facilitate high resolution EMS to the HCI applications, without the need for complex and time-consuming calibration procedures.

15

20

We achieve 52% replay accuracy. Across the three most accurate poses, we achieve 82% replay accuracy. The most accurate poses (Hand-Right and Wrist-Down) are replayed with 89% accuracy. In both of these instances, the error case moved in the direction of the pose's antagonist muscle. Holding a pose can lead to agonist-antagonist co-activation and therefore create EMG signals across the two muscle compartments. We successfully identified these muscle compartments in 67% of gestures.

25

30

These results demonstrate the possibility of using EMG to auto-calibrate EMS arrays and use of the calibration method for increasingly complex gestures.

The described calibration procedure takes approximately 1 minute per pose (45 seconds to gather EMG data and 15 seconds for amplitude exploration.) Furthermore, a relatively high accuracy of the 'index-point' gesture was obtained. This is the most complex pose in the study in terms of muscle recruitment. The 'index point' gestures
5 involves folding three fingers and extending a fourth. This is achieved by isolating the individual finger 'slips' of the underlying shared muscle groups.

The relatively high accuracy of the index-point gesture demonstrates that calibration of advanced poses can be achieved with the EMG-calibration technique with no increase
10 in calibration time.

Example 3: Improved resolution and faster calibration

Example 2 demonstrated the potential of auto-calibrating EMS arrays with EMG. The array and calibration of the current invention further has the potential of improving the resolution. The results of Example 2 demonstrate the possibility of using EMG to auto-
15 calibrate EMS arrays and use of the calibration method for increasingly complex gestures.

In Example 2, for 67% of the gestures the EMG-EMS mapping correctly identified the muscle compartments involved in performing the gesture. When holding a pose, co-activation can cause EMG potentials across the two muscle compartments. However, where agonist muscle potentials increase over time, antagonist muscles do not. Better modeling of agonist-antagonist behaviors, such as monitoring changes in certain electrodes over time, may improve the overall accuracy of the proposed calibration
20 technique.

The least successful gesture in Example 2 was Hand-Left, with only 11% accuracy, or one correct replay. A principle muscle in the production of this gesture, also called a radial deviation, is the flexor carpi radialis. This muscle runs up the center underside of
30 the forearm, roughly in-line with typical positioning of the zip, as illustrated in Figure 1B.

For this reason, the electrodes proximal to the zip would have measured comparatively high EMG potentials, due to skin surface capacitance, while being physically positioned over neighboring muscles. Any stimulation applied through those electrodes would
35 have stimulated neighboring muscles, in this case those involved in our Wrist-down

gesture. This can be seen as 55% of the Hand-left gestures resulted in a Wrist-down motion.

5 It is important, therefore, to consider areas of the skin that are not covered by electrodes, such as underneath fabric fasteners. The effect of these areas on calibration accuracy is two-fold. Firstly, as those muscles are not covered by an electrode, they cannot be directly targeted with stimulation. Secondly, without electrodes directly over the muscles to record high potentials, the neighboring electrodes may appear comparatively high, resulting in their selection for stimulation.
10 This will likely lead to inaccurate stimulation results.

In the study of Example 2, the participants increased one channel of amplitude to explore the generated pattern. This channel automatically maintained a calculated ratio to the amplitude of the second channel (based on differences in measured EMG
15 potentials). This may have had a negative impact on our results. After participating in the study, one participant re-visited the stimulation patterns with individually-controllable channel amplitudes. This participant was able to correctly perform, or improve, the accuracy of certain stimulation patterns with this technique. This suggests the need for a further exploration of the automatically calculated amplitude ratios.

20 The participants also did not vary the pulse widths and frequencies per channel, but instead used the pre-defined values (55Hz and 200 μ s). As varying parameters can target different muscle depths, this can result in increased accuracies for given stimulation patterns. Automatically determining stimulation frequencies from the EMG
25 data is a prospect, but requires higher sampling rate than what is achieved in the current study.

As electrodes spanned the entirety of the forearm, many of the generated stimulation patterns utilized electrodes closer to the wrist than previously explored. One reason for
30 this may be the reading direction of the sleeve - from the top of the sleeve to the bottom of the sleeve. During sub-maximal contraction, EMG amplitudes increase over time. This favors the electrodes towards the wrist, increasing their likelihood of selection for stimulation. It may be possible to reduce the impact of this by randomizing the order in which electrodes are read across the sleeve. Another approach may be to

take sparsely-sampled repeat readings, from which to normalize the EMG amplitudes across the sleeve.

5 The accuracy of the calibration process results from the accuracy of the EMG data. In our prototype, there is a distance of approximately 1.5m between the EMG source and the signal amplification circuitry. By moving the amplifiers closer to the source of the signal, e.g. by embedding them into the sleeve itself, an improved EMG data resolution may be obtained.

10 Higher resolution, data rate, and calibration accuracy may also be obtained by using alternative hardware to the Arduino Mega, such as a 5kHz EMG and a 16-bit analog to digital converter (ADC). Improving these factors would increase our EMG resolution and enable higher calibration accuracy.

15 Although the calibration time represents an improvement over existing techniques, 1 minute-per-pose is not the lowest time bound for this technique. The EMG devices used in our study perform raw signal processing and windowing on-board, and, due to the spike in the signal when switching relays, result in the 220ms read time per electrode pair. By moving raw signal processing to software, we can reduce our
20 electrode pair read time from 220ms to ~50ms without loss of data resolution. This brings our per-pose calibration time closer to 30 seconds with two off-the-shelf devices (15 seconds of data capture, 15 seconds of amplitude exploration). With more devices, this can be reduced up to the point where muscles can be read and electrode patterns calculated in interactive time.

25 Improved resolution may also be obtained by reducing the noise. Noise in EMG sensing as described previously for the sensing resolution, may be reduced by the user re-run the EMG calibration process. Alternatively, the multi-electrode stimulation style requires many (ca. 1018) steps for manual calibration.

30 After the study described in Example 2, some participants were given a basic GUI for selecting electrodes and controlling stimulation parameters, in order to further explore the capabilities of the sleeve. We expected the participants to consider their underlying musculature and make informed electrode selections, but we saw no evidence of this.
35 Instead, participants would make seemingly random selections to 'see what happened'.

Even with the underlying anatomical knowledge, the inventors were no more successful in manually calibrating the participants, in part due to the underlying anatomical differences, and in part due to the lack of haptic and motor feedback.

5 The method of the current invention includes reading between each electrode and its six neighboring electrodes. This is in order to improve reading accuracy along muscles that do not tend directly down the arm (pennate muscles, for example). This adds a complexity to our mapping procedure, as at any given electrode location, we do not know which electrode pair to favor.

10

While we assume that electrodes directly down the muscle body will provide the highest readings, this is a potential source for noise and error in our modeling. Since the muscle structure under the electrodes cannot be determined, it may be beneficial to move from a bipolar EMG configuration to a monopolar configuration (gathering EMG data from individual electrodes). This has recently been shown to offer increased accuracy over a bipolar approach when processing data from the 5th principle component.

15

The calibration approach of the present invention is a “per-pose” technique. Alternatively, an “all-possible-movements” approach may be advantageous. The “all-possible-movement” approach is based on calibration data including random walk technique based on which calculation of the stimulation required to achieve any desired pose (within their possible joint-selection space) is obtained. Thus, with this approach all desired gestures need not to be designed ‘ahead of time’ and no underlying muscle knowledge is required.

25

The calibration of the current array may include an all-possible-movements approach. This may be obtained by increasing the number of EMG devices used, and therefore approaching real-time EMG tracking. Thus, the EMG-calibration technique presented here could be moved from a per-pose to an all-possible-movements approach. For example, the user could put on the sleeve, and wiggle their fingers and roll their wrist in a specified pattern, while EMG data is collected, in order to arrive at a complex calibration mapping. Stimulation amplitudes would still require exploration; however, this could then be explored as an iterative loop between EMS and EMG in real time, with EMG readings being taken between EMS stimulation pulses.

30

35

Example 4: Circuit and fabrication of circuit

Example 4 demonstrates the fabrication of an embodiment of the invention; a sports sleeve comprising 60 electrodes and related circuitry. Figure 8 shows the circuit design
5 for this embodiment, while Figure 3 shows an abstracted configuration of the whole design.

The design consists of an EMS device with two channels and two single-channel EMG devices. The circuit board (as shown in Figure 8) controls selecting electrodes for
10 either EMG or EMS. The signal switching board (Figure 3, center left), then connects directly to a sports sleeve consisting of 60 electrodes.

The electrodes are individually sewn into the sleeve and are constructed from conductive fabric. The electrodes interface to the exterior of the sleeve with metal
15 poppers. The metal poppers are individually connected to the circuitry (as can be seen in Figure 1, left). The circuitry is controlled by a micro-controller. Figure 7 details a high-level overview of the control process.

References

- 20 [1] EP3184143
[2] WO 2012/003451

Claims

1. A wearable garment fabric for electric muscle stimulation (EMS) comprising:
 - an array of electrodes, wherein the electrodes are configured for multi-channel electromyography (EMG) and multi-channel EMS pulses,
 - an EMG control system configured for collecting EMG data within the electrode array when the fabric wearer makes a muscle(s) pose, and
 - an EMS control system configured for generating EMS pulses within the electrode array to replay the muscle(s) pose, wherein the EMS pulses are calibrated based on the collected and processed EMG data.
2. The fabric according to claim 1, wherein the EMG control system is configured to collect the EMG data within the electrode array in a monopolar manner.
3. The fabric according to claim 1, wherein the EMG control system is configured to collect the EMG data within the electrode array in a bipolar manner.
4. The fabric according to claim 3, wherein the EMG control system is configured to collect bipolar EMG readings between each electrode and six neighbouring electrodes.
5. The fabric according to claims 3-4, wherein the EMG control system is configured to collect bipolar EMG readings between each electrode and the three closest electrodes in two adjacent rows.
6. The fabric according to claims 3-5, wherein the EMG control system is configured to collect bipolar EMG readings between each electrode assigned as anode and six neighbouring cathodes.
7. The fabric according to claims 4-6, wherein the EMG control system is configured to cluster each electrode pair using k-means clustering.
8. The fabric according to claim 7, wherein the EMS control system is configured to generate EMS pulses based on the clustered EMG data.

9. The fabric according to claims 7-8, wherein the EMS control system is configured to generate EMS pulses that are multi-channel, multi-amplitude, and/or variable over time.
- 5 10. The fabric according any of the preceding claims, wherein the EMG and EMS control systems are configured to operate simultaneously, optionally by performing EMG readings between EMS pulses.
- 10 11. The fabric according to any of the preceding claims, wherein the electrodes are skin electrodes.
12. The fabric according to any of the preceding claims, wherein the array of electrodes comprises above 10 electrodes, more preferably between 20 to 80 electrodes, such as 60 electrodes, and most preferably above 100 electrodes.
- 15 13. The fabric according to any of the preceding claims, wherein the array of electrodes are placed in one or more rows thereby forming a grid, such as six rows where each row comprises ten electrodes.
- 20 14. The fabric according to any of the preceding claims, wherein the contact surface area of each electrode is between 0.4 to 10 cm², more preferably between 0.5 to 5 cm², and most preferably is between 0.8 to 4 cm², such as 1 or 3 cm².
- 25 15. The fabric according to any of the preceding claims, wherein the shape of the electrodes are selected from the group of: rectangular, circular, oval, squared shaped, and stud shaped, and most preferably is rectangular shaped or stud shaped.
- 30 16. The fabric according to any of the preceding claims, wherein the size of the electrodes correspond to a rectangular electrode with a first length between 10 to 30 mm, such as 20 mm, and a second length between 10 to 30 mm, such as 15 mm.
- 35 17. The fabric according to any of the preceding claims, wherein the distance between neighbouring electrodes is between 5 to 30 mm, more preferably between 10 to 20 mm, and most preferably between 10 to 15 mm.

18. The fabric according to any of the preceding claims, wherein the contact surface area of the electrodes cover the fabric with a coverage degree between 10 to 99%, more preferably between 50 to 90%, and most preferably between 60 to 80%.
- 5
19. The fabric according to any of the preceding claims, wherein the fabric is configured to cover one or more muscle(s) groups.
20. The fabric according to claim 19, wherein the fabric is configured as a sleeve to cover the entire forearm.
- 10
21. A method for calibrating EMS for a muscle(s) pose, comprising the steps of:
- mounting the wearable fabric according to claims 1-20 on a user,
 - providing the target muscle(s) pose,
 - 15 - collecting EMG data within the electrode array simultaneously with the muscle(s) pose,
 - clustering the EMG data using k-means clustering,
 - providing EMS pulses within the electrode array based on the clustered EMG data, whereby the desired muscle(s) pose is obtained.
- 20
22. A computer implemented method for providing an EMS input to a wearable fabric according to claims 1-20, comprising the steps of:
- collecting EMG data within the electrode array,
 - clustering the EMG data using k-means clustering,
 - 25 - providing EMS pulses within the electrode array based on the clustered EMG data, whereby an EMS input is obtained.
23. A circuit for multiplexing EMG and EMS signals from an array of electrodes, comprising:
- 30
- at least one EMG unit,
 - at least one EMS unit for controlling EMS amplitude, pulse width and frequency,
 - one or more switching boards for switching between electrodes,
 - at least one switch board for switching between EMG and EMS mode.
- 35
24. The circuit according to claim 23, comprising two EMG units and one EMS unit.

25. The circuit according to any of claims 23-24, configured to be used as the EMG and/or EMS control system of any of claims 1-20.

5 26. The circuit according to any of claims 23-25, configured to carry out the method of claim 22.

27. The circuit according to any of claims 24-27, further comprising a user interface, such as a GUI, configured for receiving input for modifying the EMS pulses.

10 28. A computer system, such as a mobile device, comprising a processor and a memory and being adapted to carry out the method of claim 22.

15

1/7

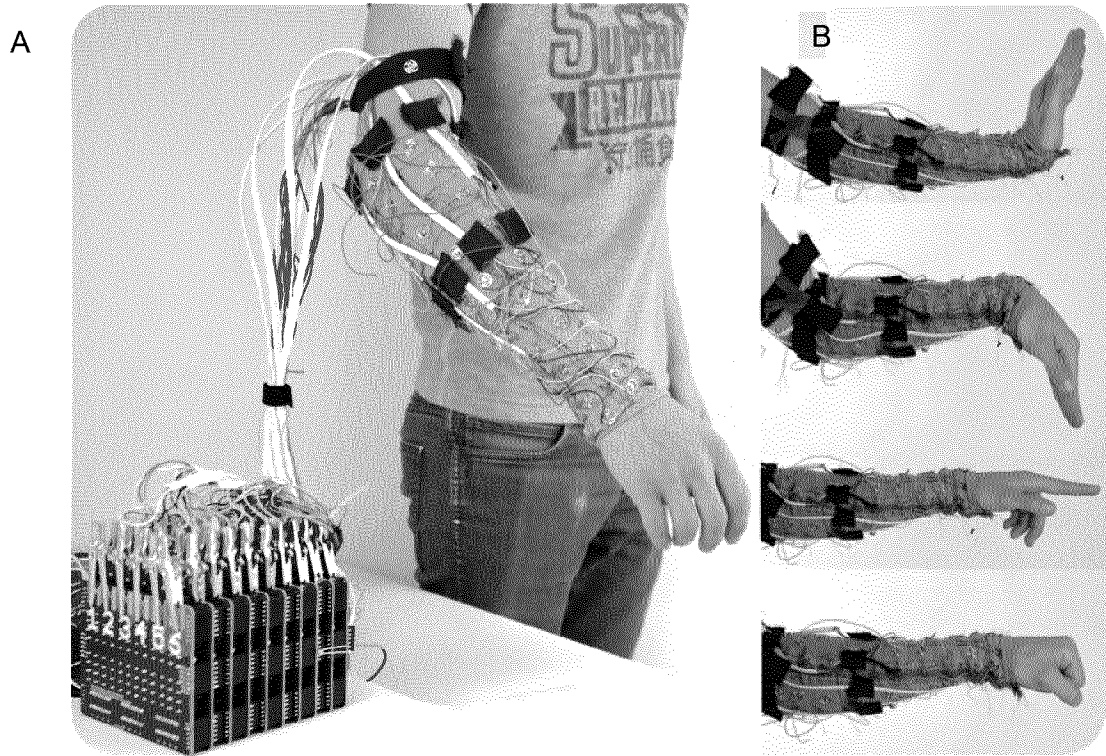


Fig. 1

2/7

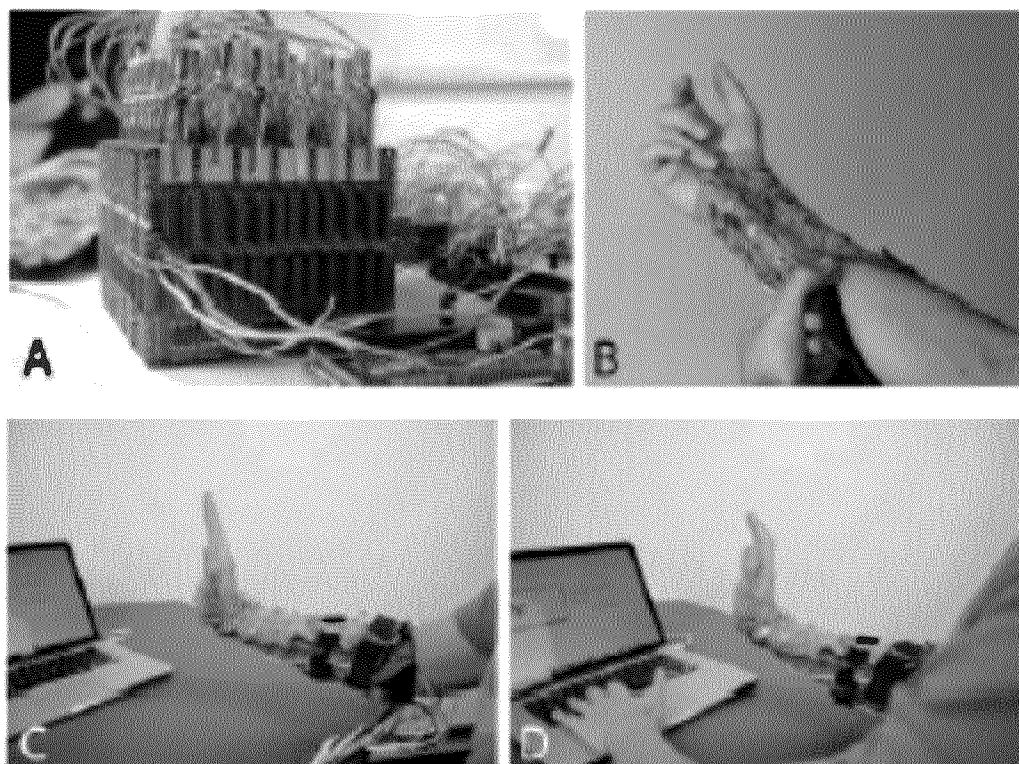


Fig. 2

3/7

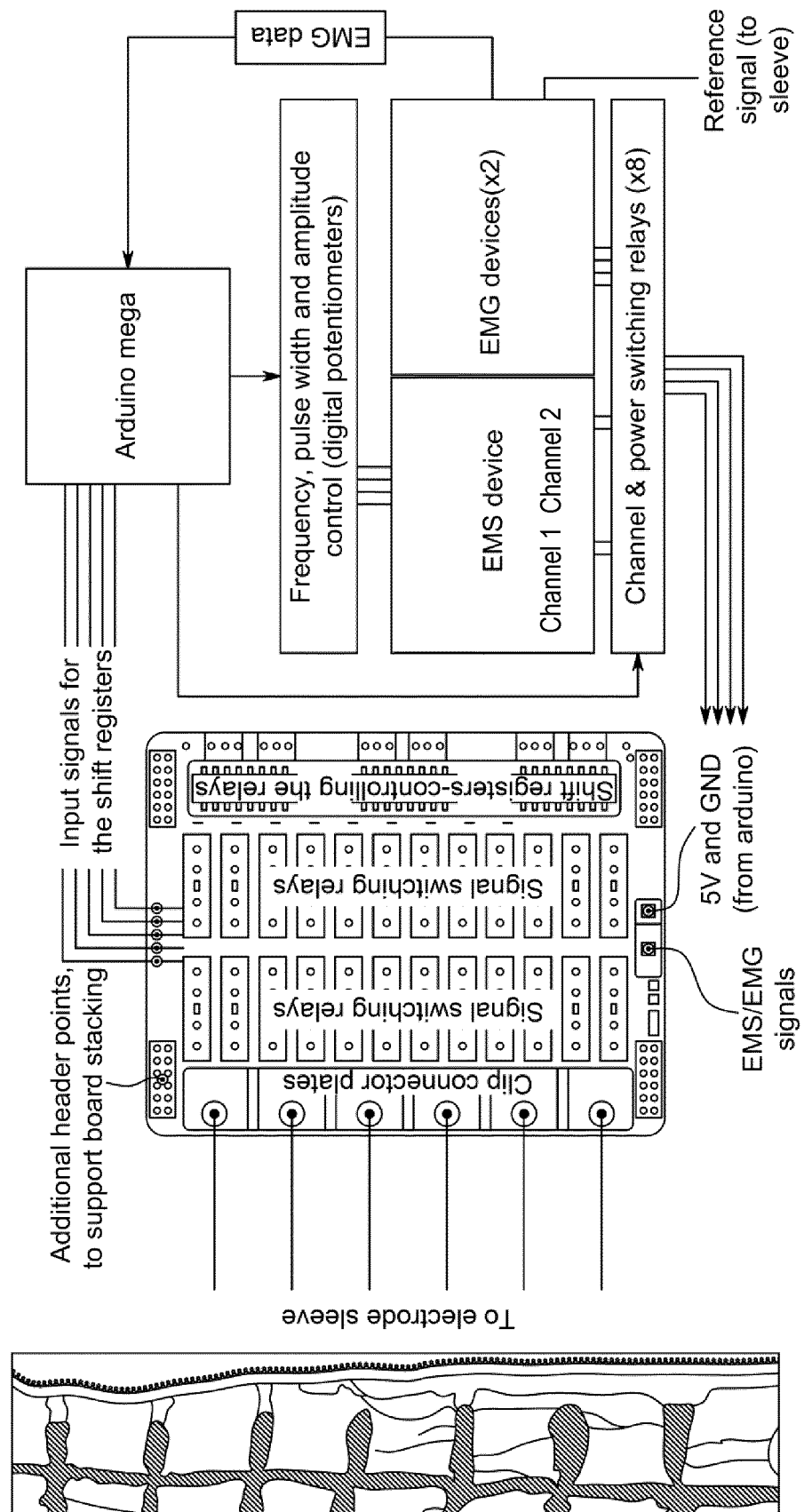


Fig. 3

SUBSTITUTE SHEET (RULE 26)

4/7

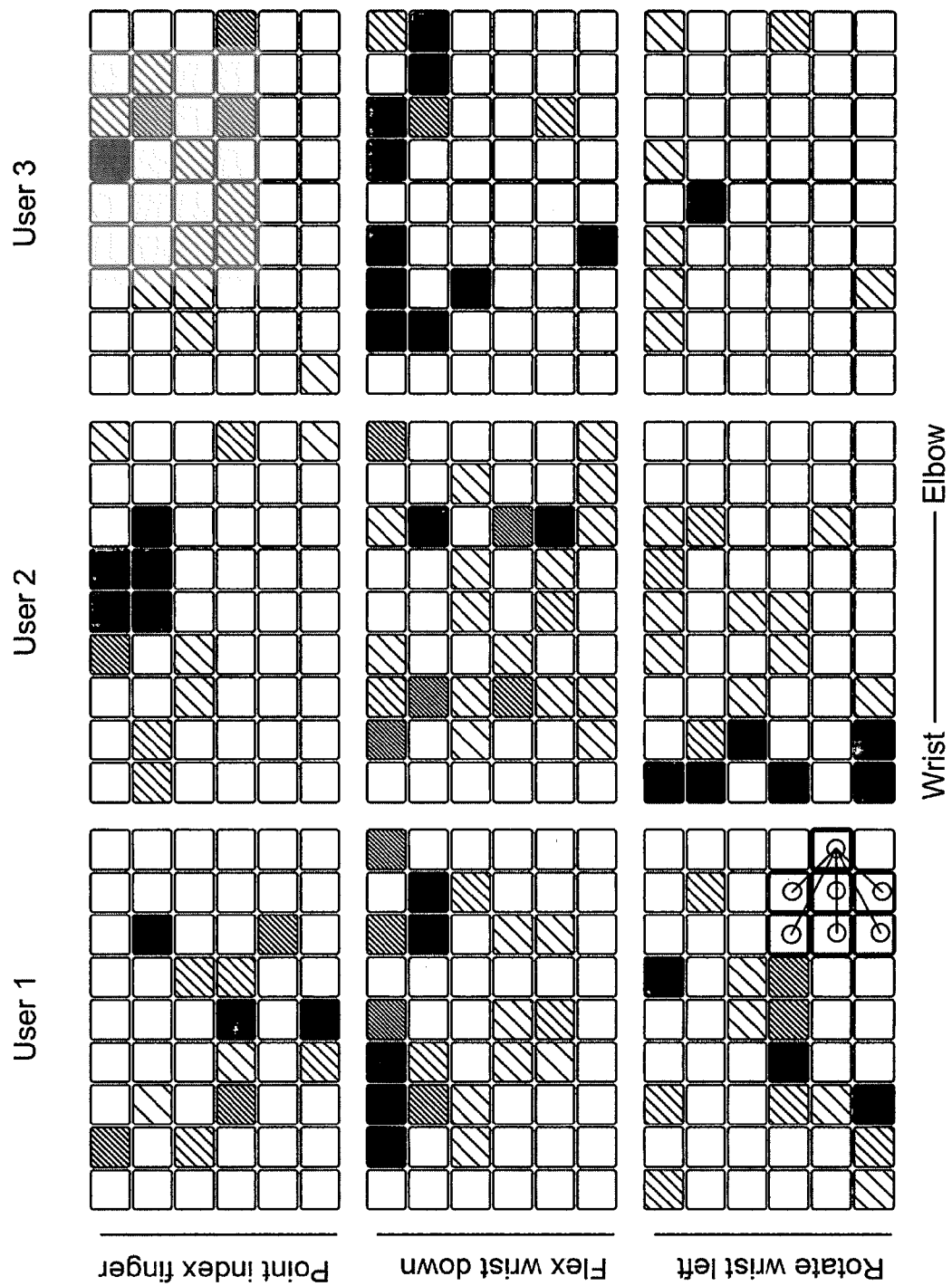


Fig. 4

5/7

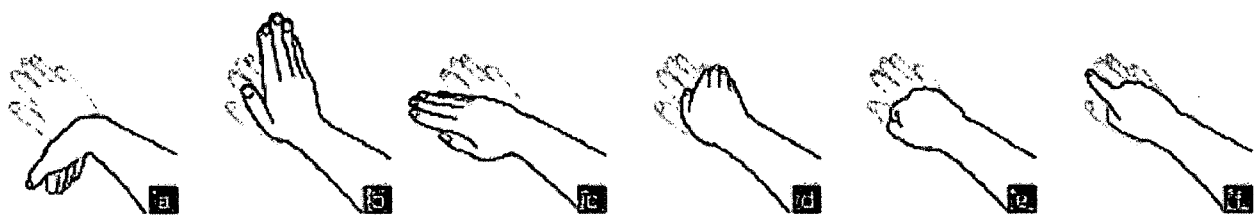


Fig. 5

		<u>Produced</u>						
		Wrist-up	Wrist-down	Hand-left	Hand-right	Index-point	Squeeze-fingers	Neutral
<u>Requested</u>	Wrist-up	2	4	2	1			
	Wrist-down	1	8					
	Hand-left	1	5	1	2			
	Hand-right			1	8			
	Index-point	3				6		
	Squeeze-fingers	1		2			3	3

Fig. 6

6/7

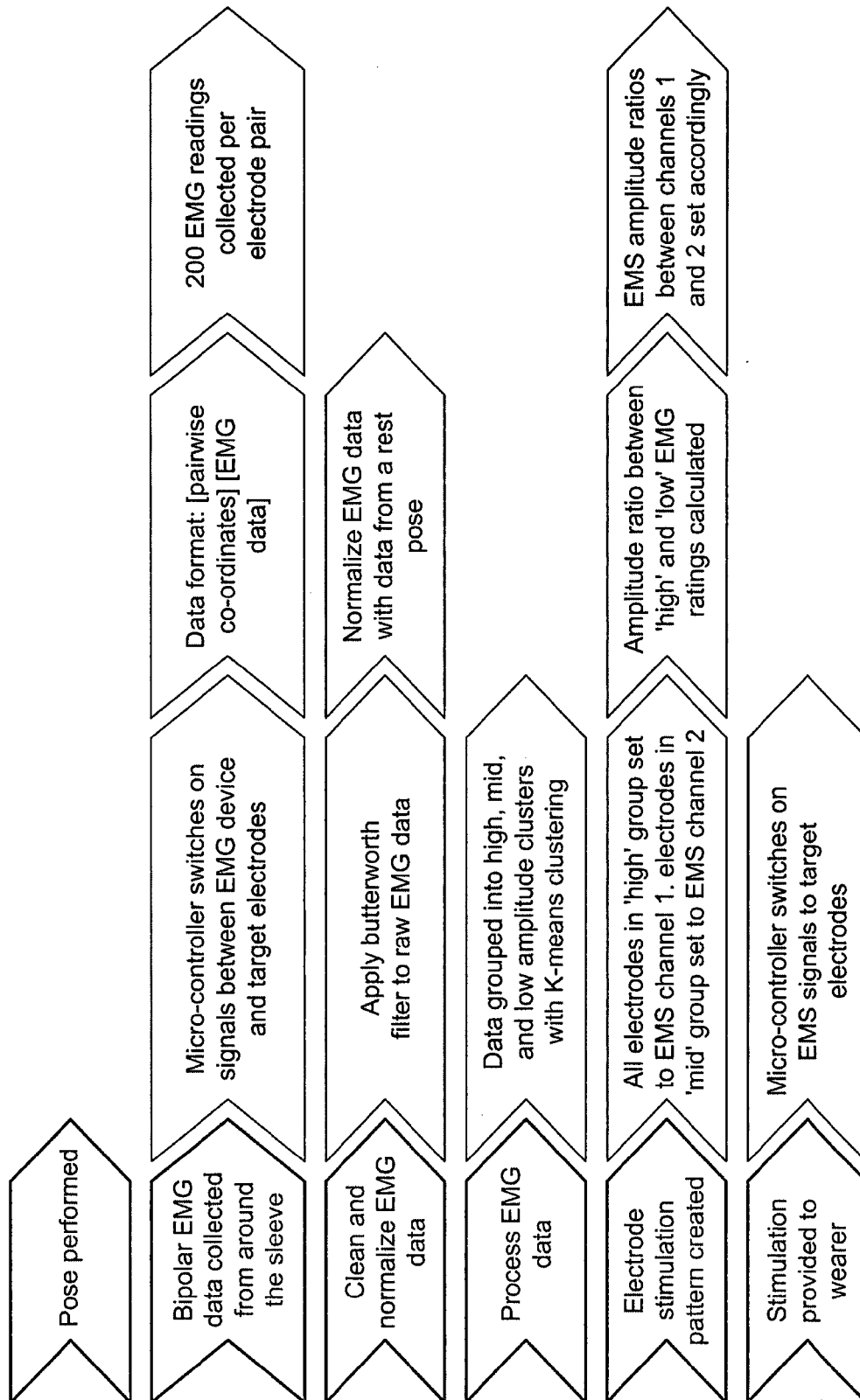


Fig. 7

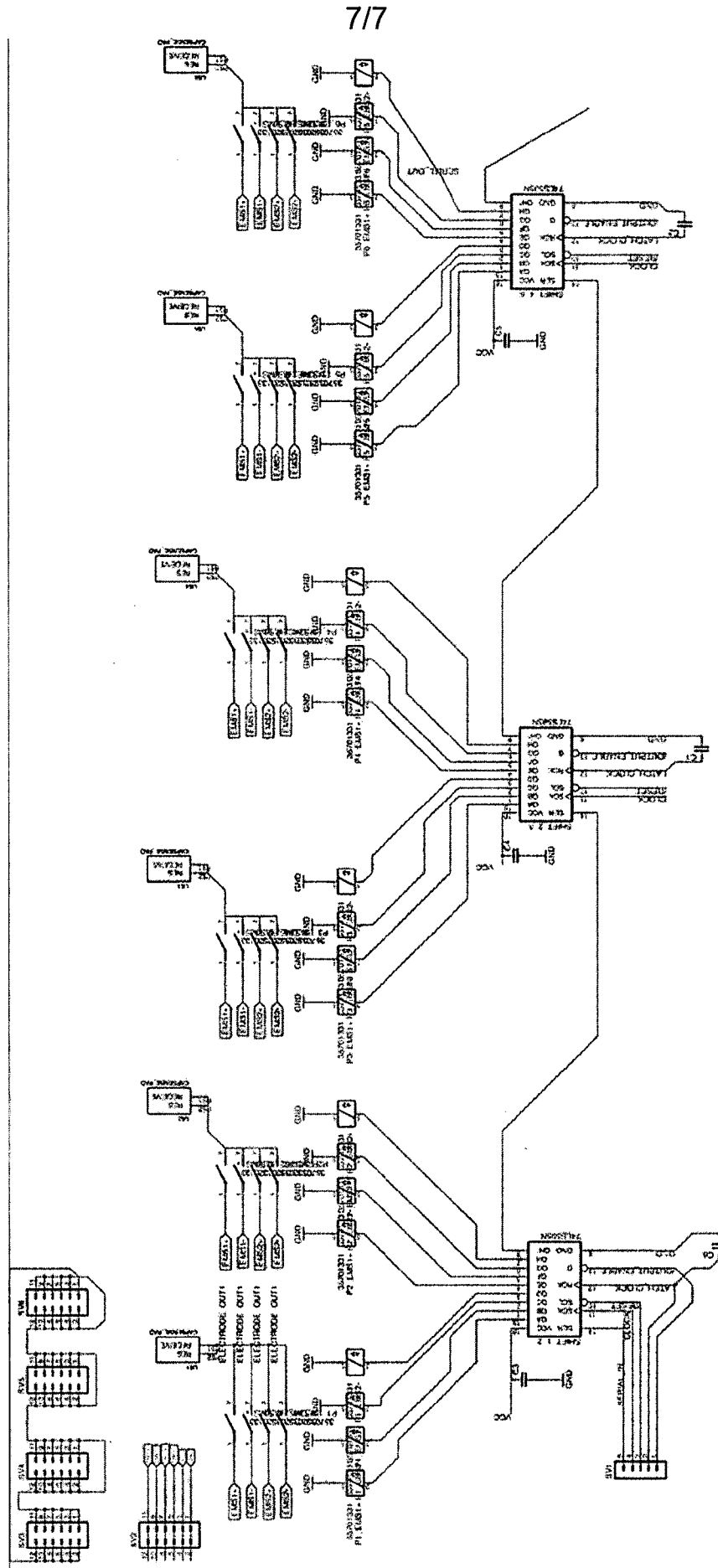


Fig. 8

SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/073452

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/04 A61N1/36
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)
A61N

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.
X	WO 2016/196801 A1 (BATTELLE MEMORIAL INSTITUTE [US]) 8 December 2016 (2016-12-08)	1-15, 17-20, 23-28
Y	abstract; figures 1, 4, 14, 24 paragraphs [0079], [0093], [0110]	16
Y	----- WO 2011/067327 A1 (INTERVENTIONS AB [SE]; LUNDQVIST FREDRIK [SE]) 9 June 2011 (2011-06-09) abstract; figure 7	16
X	----- WO 2016/131936 A2 (WEARABLE LIFE SCIENCE GMBH [DE]) 25 August 2016 (2016-08-25) the whole document	1
A	----- WO 2016/131926 A1 (WEARABLE LIFE SCIENCE GMBH [DE]) 25 August 2016 (2016-08-25) the whole document	1-20, 23-28



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

12 October 2018

Date of mailing of the international search report

22/10/2018

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Wetzig, Thomas

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2018/073452

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 21, 22
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/073452

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016196801 A1	08-12-2016	EP 3302686 A1 US 2018154140 A1 WO 2016196801 A1	11-04-2018 07-06-2018 08-12-2016
WO 2011067327 A1	09-06-2011	EP 2512590 A1 JP 2013512709 A SE 1050420 A1 US 2012245483 A1 WO 2011067327 A1	24-10-2012 18-04-2013 26-07-2011 27-09-2012 09-06-2011
WO 2016131936 A2	25-08-2016	CN 107529995 A EP 3259016 A2 US 2018036531 A1 WO 2016131936 A2	02-01-2018 27-12-2017 08-02-2018 25-08-2016
WO 2016131926 A1	25-08-2016	CN 107530545 A EP 3259026 A1 US 2018093095 A1 WO 2016131926 A1	02-01-2018 27-12-2017 05-04-2018 25-08-2016