

PROSTHESIS

5 The invention relates to a prosthesis for replacing a missing extremity of a living being, particularly a human being. The prosthesis has prosthetic links driven by means of actuators.

10 The prostheses driven by actuators available today, for example hand/arm prostheses, are associated with high procurement costs. Moreover, these prostheses are limited in their function.

The object of the invention is to provide an improved prosthesis to replace a missing extremity of a living being, particularly a human being, which is economical to produce and has expanded functionality.

15 The invention results from the features of the main claims. Advantageous further embodiments and designs are the subject matter of the dependent claims. Further features, application options, and advantages of the invention result from the following description, and explanation, of exemplary embodiments of the invention, which are represented in the figures.

20 The invention is achieved with a prosthesis for replacing a missing extremity of a living being, particularly a human being. The proposed prosthesis comprises one or more prosthetic links driven by means of actuators, wherein the proximal prosthetic link has a mechanical interface for fixing the proximal prosthetic link to the living being.

25 The prosthesis further comprises first sensors, which sense a current state $ZUS(t)$ of the prosthesis, particularly a state of contact between the prosthesis and the environment. Advantageously, the first sensors comprise one or more of the following sensors: Joint sensor(s) for sensing a motor position and/or a motor speed and/or a motor acceleration,
30 output sensor(s) for sensing an output position and/or an output speed and/or an output acceleration, acceleration sensor(s), for example for sensing an acceleration in the joints of the prosthesis or an acceleration in the prosthetic links, the acceleration due to gravity, an acceleration and motion of the mechanical interface for fixing the proximal prosthetic link, a relative acceleration and motion of the prosthesis on the residual limb, force

sensor(s) for determining the forces transferred to an environment due to the individual prosthetic links and for determining forces transferred from an environment onto the individual prosthetic links as well as for determining interaction forces between the prosthesis and the prosthesis wearer, torque sensor(s) for determining the torques transferred to an environment by the individual prosthetic links and for determining torques transferred from an environment to the individual prosthetic links, tactile sensor(s), particularly an artificial skin, for local sensing of acting forces and torques, temperature sensor(s) for sensing temperatures acting upon the prosthesis, humidity sensor(s) for sensing humidity acting upon the prosthesis. All sensors (including individual ones) may also advantageously be used to determine mechanical relations (forces, accelerations, etc.).

The prosthesis further comprises an interface to second sensors, which sense biosignals $SIG_{BIO}(t)$ in the living being for controlling the missing extremity. The second sensors advantageously comprise one or more electromyography sensors and/or one or more electroencephalography sensors. The individual second sensors are advantageously either applied to the living being or implanted in the living being.

The prosthesis further comprises third sensors for sensing data $D_{UMG}(t)$, which describe a current environment of the prosthesis, particularly objects and/or other living beings located in the environment. The third sensors may comprise one or more of the following sensors: optical sensors, for example camera or video sensors, ultrasound sensors, laser sensors, etc.

The prosthesis further comprises a prediction unit, which determines a model $M_A(t)$ of an action A to be performed by means of the prosthesis on the basis of the biosignals $SIG_{BIO}(t)$ and the state $ZUS(t)$ of the prosthesis and the data $D_{UMG}(t)$ and predicts motions $B_{eweg}(M_A(t))$, dependent on the model $M_A(t)$, of the prosthetic links for a time period $[t, t+\Delta t]$. In the simplest case, the prediction takes place for a next period of time. This can be the control cycle or control cycles of the prosthesis. The prediction time period Δt is advantageously selected in a range of from 0.3 to 30 seconds. The prediction time period Δt may advantageously vary depending on the processor load in the prediction unit. Advantageously, the prediction unit is designed and set up such that the sensing of model $M_A(t)$ and/or $M_{A'}(t)$ is implemented as a learning-capable process, which autonomously

learns motions $B_{\text{eweg}}(M_A(t))$ / $B_{\text{eweg}}(M_{A'}(t))$ of the prosthetic links based on historical data, for executing an action A/A' for this. They may also consider predicted/estimated contact and/or other multimodal information.

- 5 The prosthesis further comprises an evaluating unit, by means of which the discrete decision E to replace the action A with another action $A'(E)$ can be determined on the basis of an evaluation of the biosignals $SIG_{\text{BIO}}(t)$, of the state $ZUS(t)$, of the data $D_{\text{UMG}}(t)$ and of the predicted motions $B_{\text{eweg}}(M_A(t))$ in accordance with a specified evaluation scheme, wherein the action $A'(E)$ can define a reflexive and/or protective motion of the
- 10 prosthesis that is autonomously controlled in an open-loop/closed-loop manner, and wherein, if the action $A'(E)$ does not define such a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner, the prediction unit determines a model $M_{A'}(t)$ of the action A' to be performed by means of the prosthesis and predicts motions $B_{\text{eweg}}(M_{A'}(t))$, dependent on the model $M_{A'}(t)$, of the
- 15 prosthetic links for a time period $[t, t+\Delta t]$.

The evaluating unit is advantageously designed and set up such that a decision E for an action $A'(E)$, which defines a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner independently of the

20 biosignals $SIG_{\text{BIO}}(t)$, is determined on the basis of the current state $ZUS(t)$ and/or of the data $D_{\text{UMG}}(t)$.

The evaluating unit is advantageously designed and set up such that a decision E for an action $A'(E)$, which defines a reflexive and/or protective motion of the prosthesis that is autonomously controlled, is then triggered when

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- a current motion of the prosthetic links deviates from the predicted motion $B_{\text{eweg}}(M(t))$ or $B_{\text{eweg}}(M_{A'}(t))$ of the prosthetic links by more than a specified limit (this limit may be time-variant and/or depend on the state $ZUS(t)$); and/or
 - a current motion of the prosthetic links deviates from a learned model, which observes
- 30 the nominal states of the prosthesis and corresponding critical deviations from the nominal states; and/or
- it is discernible based on the current state $ZUS(t)$ and the data $D_{\text{UMG}}(t)$ that the action A or $A'(E)$ to be executed with the prosthesis was not or will not be executed or was or will be executed in a flawed manner (thereby, for example, a re-grasping can occur when

there is a faulty grasping of an object by the prosthesis); and/or

- an unintentional collision of one or more prosthetic links with an object in the environment has occurred or will occur; and/or

- a temperature recorded by a temperature sensor of the prosthesis reaches or exceeds a limit; and/or

- a distal end of the prosthesis has approached an object up to a specified distance or environment envelope (this is used particularly for executing so-called standard skills such as, for example, the (partially) autonomous grasping of an object, the moving of a key on a keyboard, opening of a door, the grasping and bringing to the mouth of a bottle of beer, etc.); and/or

- the current state $ZUS(t)$ of the prosthesis corresponds to a state to which the following applies: $ZUS(t) \notin \underline{Z}_{ZUS,erlaubt}$, wherein $\underline{Z}_{ZUS,erlaubt}$ indicates the quantity of all allowed states $ZUS(t)$ – ($ZUS(t)$ may also be derived variables. Thus, any varieties, observing elements, models can be learned with methods of autonomous learning).

The prosthesis finally comprises a control unit, which derives control signals $Sig(t)$ for controlling the actuators and controls/regulates the actuators based on the control signals $Sig(t)$, based on the currently valid, predicted motions $B_{eweg}(M_A(t))$ or $B_{eweg}(M_{A'}(t))$ or based on the reflexive and/or protective motion autonomously controlled in an open-loop/closed-loop manner.

Through evaluation of the $SIG_{BIO}(t)$, through use of the listed sensors to sense the current state $ZUS(t)$ of the prosthesis and a state of an environment of the prosthesis, and through model formation and prediction, the proposed prosthesis enables an improved and more natural control of the prosthesis, wherein the prosthesis is capable of performing autonomous motions and actions, particularly reflexive and/or protective autonomous motion.

An advantageous refinement of the prosthesis is characterized in that the control unit has an input interface, by means of which a user of the prosthesis prompts, by means of an input, the control unit to stop any sort of motion of the prosthesis. This enables the wearer of the prosthesis to stop an activity of the prosthesis at any time.

An advantageous refinement of the prosthesis is characterized in that the control unit is

- designed and set up such that a further motion of the prosthesis takes place based on currently sensed biosignals $SIG_{BIO}(t)$ and/or after an input of a user of the prosthesis by means of an interface of the control unit after an execution of a reflexive and/or protective autonomous motion, wherein the interface is designed and set up for manual optical and/or
- 5 acoustic and/or tactile input. Advantageously, the control unit is formed from multiple multimodal control units. It is further advantageous when the control unit is designed and set up such that the control system of the actuators has torque control with friction compensation and/or an impedance regulation and/or a force regulation.
- 10 An advantageous refinement of the prosthesis is characterized in that the control unit provides multiple apps (control programs and control parameter sets) for controlling the prosthesis, wherein each app defines an operating mode of the prosthesis, and wherein the control unit has an interface, particularly a wireless interface, to a mobile unit, by means of which a respective app can be selected and configured for controlling the prosthesis.
- 15 The mobile unit is advantageously a notebook or a smart phone or a mobile tablet computer.

An advantageous refinement of the prosthesis is characterized in that the control unit is designed and set up such that an automatic adapting of the mechanical active and/or

20 passive impedance, particularly the stiffness of the prosthesis, takes place through a corresponding change in the control signals $Sig(t)$, based on the current state $ZUS(t)$ and the data $D_{UMG}(t)$.

The proposed prosthesis is advantageously designed as a hand prosthesis, an underarm

25 prosthesis with and without elbows, a complete arm prosthesis, a leg prosthesis, or a prosthesis with an exoskeleton. One, more, or all of the prosthetic links with the proposed prosthesis can be driven by means of actuators.

An advantageous refinement of the prosthesis is characterized in that a response interface

30 is available, by means of which feedback on the current state $ZUS(t)$ of the prosthesis and its interaction with the environment is transmitted to the prosthesis wearer. This feedback occurs preferably haptically or through electrical stimulation.

Other advantages, features, and details result from the following description, in which at least one exemplary embodiment is described in detail – optionally with reference to the drawing. Equivalent, similar, and/or functionally equivalent parts have been given the same reference numbers.

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In the drawings:

Figure 1 shows a schematic diagram of a proposed prosthesis.

10 **Figure 1** shows a schematic diagram of a proposed prosthesis to replace a missing extremity of a living being, particularly of a human being, which has: one or more prosthetic links driven by means of actuators **101**, wherein the proximal prosthetic link has a mechanical interface for fixing the proximal prosthetic link to the living being; first sensors **102**, which sense a current state $ZUS(t)$ of the prosthesis, particularly a state of
15 contact between the prosthesis and an environment; an interface to second sensors **103**, which sense biosignals $SIG_{BIO}(t)$ of the living being to control the missing extremity; third sensors **104** for sensing data $D_{UMG}(t)$, which describe a current environment of the prosthesis, particularly objects and/or other living beings in the environment; a prediction unit **105**, which determines, based on the biosignals $SIG_{BIO}(t)$ and on the state $ZUS(t)$ of
20 the prosthesis and on the data $D_{UMG}(t)$, a model $M_A(t)$ of an action A to be executed with the prosthesis and predicts motions $B_{eweg}(M_A(t))$, dependent on the model $M_A(t)$, of the prosthetic links for a period of time $[t, t+\Delta t]$; an evaluating unit **106** by means of which the discrete decision E to replace the action A with another action $A'(E)$ can be determined on the basis of an evaluation of the biosignals $SIG_{BIO}(t)$, of the state $ZUS(t)$,
25 of the data $D_{UMG}(t)$, and of the predicted motions $B_{eweg}(M_A(t))$ in accordance with a specified evaluation scheme, wherein the action $A'(E)$ can define a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner, and wherein, if the action $A'(E)$ does not define such a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner, the prediction unit **105** determines a model $M_{A'}(t)$ of the action
30 A' to be performed by means of the prosthesis and predicts motions $B_{eweg}(M_{A'}(t))$, dependent on the model $M_{A'}(t)$, of the prosthetic links for a time period $[t, t+\Delta t]$; and a control unit **107**, which derives control signals $Sig(t)$ for controlling the actuators and controls/regulates the actuators based on the control signals $Sig(t)$, based on the currently

valid, predicted motions $B_{\text{eweg}}(M_A(t))$ or $B_{\text{eweg}}(M_{A'}(t))$ or based on the reflexive and/or protective motion autonomously controlled in an open-loop/closed-loop manner.

5 Although the invention has been illustrated and explained in more detail by means of preferred exemplary embodiments, the invention is not limited by the disclosed examples and other variations may be derived by one of ordinary skill in the art without extending beyond the protective scope of the invention. It is thus clear that a plurality of variation options exist. It is likewise clear that exemplary embodiments actually only represent examples, which are not to be interpreted in any manner as a limitation, for example, of
10 the protective scope, the use options, or the configuration of the invention. Rather, the previous description and the description of figures should make one of ordinary skill in the art capable of specifically implementing the exemplary embodiments, wherein one of ordinary skill in the art with knowledge of the disclosed concept of the invention can undertake various changes, for example with respect to the function or the arrangement
15 of individual elements listed in an exemplary embodiment, without going beyond the scope of protection, which is defined by the claims and the legal equivalents thereof such as, for example, more extensive explanations in the description.

List of reference numbers

	101	Actuators
	102	First sensors
5	103	Second sensors
	104	Third sensors
	105	Prediction unit
	106	Evaluating unit
	107	Control unit
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CLAIMS

1. A prosthesis for replacing a missing extremity of a living being, particularly a human being, which has:
- 5 – one or more prosthetic links driven by means of actuators (101), wherein the proximal prosthetic link has a mechanical interface for fixing the proximal prosthetic link to the living being;
 - first sensors (102), which sense a current state $ZUS(t)$ of the prosthesis, particularly a state of contact between the prosthesis and the environment;
 - 10 – an interface to second sensors (103), which sense biosignals $SIG_{BIO}(t)$ in the living being for controlling the missing extremity;
 - third sensors (104) for sensing data $D_{UMG}(t)$, which describe a current environment of the prosthesis, particularly objects and/or other living beings located in the environment;
 - 15 – a prediction unit (105), which determines a model $M_A(t)$ of an action A to be performed by means of the prosthesis on the basis of the biosignals $SIG_{BIO}(t)$ and the state $ZUS(t)$ of the prosthesis and the data $D_{UMG}(t)$ and predicts motions $B_{eweg}(M_A(t))$, dependent on the model $M_A(t)$, of the prosthetic links for a time period $[t, t+\Delta t]$;
 - an evaluating unit (106), by means of which the discrete decision E to replace the
20 action A with another action $A'(E)$ can be determined on the basis of an evaluation of the biosignals $SIG_{BIO}(t)$, of the state $ZUS(t)$, of the data $D_{UMG}(t)$, and of the predicted motions $B_{eweg}(M_A(t))$ in accordance with a specified evaluation scheme, wherein the action $A'(E)$ can define a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner, and wherein, if the action $A'(E)$ does not
25 define such a reflexive and/or protective motion of the prosthesis that is autonomously controlled in an open-loop/closed-loop manner, the prediction unit (105) determines a model $M_{A'}(t)$ of the action A' to be performed by means of the prosthesis and predicts motions $B_{eweg}(M_{A'}(t))$, dependent on the model $M_{A'}(t)$, of the prosthetic links for a time period $[t, t+\Delta t]$; and
 - 30 – a control unit (107), which derives control signals $Sig(t)$ for controlling the actuators and controls/regulates the actuators based on the control signals $Sig(t)$, based on the currently valid, predicted motions $B_{eweg}(M_A(t))$ or $B_{eweg}(M_{A'}(t))$ or based on the reflexive and/or protective motion autonomously controlled in an open-loop/closed-loop manner.

2. The prosthesis according to claim 1,
 wherein the control unit (107) has an input interface, by means of which a user of
 the prosthesis prompts, by means of an input, the control unit (107) to stop any sort
 of motion of the prosthesis.
3. The prosthesis according to either claim 1 or 2,
 wherein the evaluating unit (106) is designed and set up such that a decision E for an
 action A'(E), which defines a reflexive and/or protective motion of the prosthesis
 that is autonomously controlled in an open-loop/closed-loop manner independently
 of the biosignals SIG_{BIO}(t), is determined on the basis of the current state ZUS(t)
 and/or of the data D_{UMG}(t).
4. The prosthesis according to any of claims 1 to 3,
 wherein the evaluating unit (106) is designed and set up such that a decision E for an
 action A'(E), which defines a reflexive and/or protective motion of the prosthesis
 that is autonomously controlled, is then triggered when
- a current motion of the prosthetic links deviates from the predicted motion
 B_{eweg}(M_A(t)) or B_{eweg}(M_A'(t)) of the prosthetic links by more than a specified limit; and/or
 - a current motion of the prosthetic links deviates from a learned model, which
 observes the nominal states of the prosthesis and corresponding critical deviations from
 the nominal states; and/or
 - it is discernible based on the current state ZUS(t) and the data D_{UMG}(t) that the
 action A or A'(E) to be executed with the prosthesis was not or will not be executed or
 was or will be executed in a flawed manner; and/or
 - an unintentional collision of one or more prosthetic links with an object in the
 environment has occurred or will occur; and/or
 - a temperature recorded by a temperature sensor of the prosthesis reaches or
 exceeds a limit G2; and/or
 - a distal end of the prosthesis has approached an object up to a specified distance or
 environment envelope; and/or
 - the current state ZUS(t) of the prosthesis corresponds to a state to which the
 following applies: $ZUS(t) \notin \underline{Z}_{ZUS,erlaubt}$, wherein $\underline{Z}_{ZUS,erlaubt}$ indicates the quantity of all
 allowed states ZUS(t).

5. The prosthesis according to any of claims 1 to 4,
wherein the control unit (107) is designed and set up such that a further motion of the prosthesis takes place based on currently sensed biosignals SIG_{BIO}(t) and/or after an input of a user of the prosthesis by means of an interface of the control unit after an execution of a reflexive and/or protective autonomous motion, wherein the interface is designed and set up for manual optical and/or acoustic and/or tactile input.
6. The prosthesis according to any of claims 1 to 5,
wherein the first sensors comprise one or more of the following sensors:
- joint sensor(s) for sensing a motor position, motor speed, and/or a motor acceleration,
 - output sensors,
 - acceleration sensors,
 - force sensors for determining the forces transferred to an environment due to the individual prosthetic links and for determining forces transferred from an environment onto the individual prosthetic links as well as for determining interaction forces between the prosthesis and the prosthesis wearer,
 - torque sensors for determining the torques transferred to an environment due to the individual prosthetic links and for determining torques transferred from an environment onto the individual prosthetic links,
 - tactile sensors, particularly an artificial skin, for local sensing of effective forces and torques,
 - temperature sensors for sensing temperatures acting upon the prosthesis,
 - humidity sensors for sensing humidity acting upon the prosthesis.
7. The prosthesis according to any of claims 1 to 6,
wherein the control unit (107) provides multiple apps (control programs and control parameter sets) for controlling the prosthesis, wherein each app defines an operating mode of the prosthesis, and wherein the control unit has an interface, particularly a wireless interface, to a mobile unit, by means of which a respective app can be selected and configured for controlling the prosthesis.

8. The prosthesis according to any of claims 1 to 7,
wherein the second sensors (103) comprise one or more electromyography sensors
and/or one or more electroencephalography sensors, wherein the individual sensors
are applied to the living being or implanted in the living being.

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9. The prosthesis according to any of claims 1 to 8,
wherein the control unit is designed and set up such that an automatic adapting of
the mechanical active and/or passive impedance, particularly the stiffness of the
prosthesis, takes place through a corresponding change in the control signals $Sig(t)$,
based on the current state $ZUS(t)$ and the data $D_{UMG}(t)$.

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10. The prosthesis according to any of claims 1 to 9,
wherein the prediction unit (105) is designed and set up such that the sensing of
model $M_A(t)/M_{A'}(t)$ is implemented as a learning-capable process, which
autonomously learns motions $B_{eweg}(M_A(t))/B_{eweg}(M_{A'}(t))$ of the prosthetic links
based on historical data, for executing an action A/A' for this.

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