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Anthropomorphism in Robotics Engineering for Disabled People

B. Tondu and N. Bardou

Abstract**—**In its attempt to offer new ways into autonomy for a large population of disabled people, assistive technology has largely been inspired by robotics engineering. Recent human-like robots carry new hopes that it seems to us necessary to analyze by means of a specific theory of anthropomorphism. We propose to distinguish a functional anthropomorphism which is the one of actual wheelchairs from a structural anthropomorphism based on a mimicking of human physiological systems. If functional anthropomorphism offers the main advantage of eliminating the physiological systems interdependence issue, the highly link between the robot for disabled people and their human-built environment would lead to privilege in the future the anthropomorphic structural way. In this future framework, we highlight a general interdependence principle : **any partial or local structural anthropomorphism generates new anthropomorphic needs due to the physiological systems interdependency**, whose effects can be evaluated by means of specific anthropomorphic criterions derived from a set theory-based approach of physiological systems.

Keywords**—**Anthropomorphism, Human-like machines, Systems theory, Disability.

I. INTRODUCTION

THE recent development of humanoid robots has renewed the anthropomorphic question in robotics. Moreover it is well known that disability is since a long time a privileged field for applying robotic technology due to the high demand of increasing the disabled people autonomy through relevant technological devices [1]-[4]. The close interaction between the disabled person, the robot and the environment makes the problem of robotic assistive devices efficiency always difficult and, despite some partial successful outcomes, no definitive solution is yet appeared. We propose in the framework of this paper to apply a theoretical anthropomorphic approach to a better understanding of robotic devices possibilities for disabled people. In section 2, we introduce a general systemic working frame aimed to highlight the possible adaptive processes between the three items to be considered : the disabled, the technical device and the environment. In section 3, we discuss the anthropomorphism notion and we propose a theoretical approach based on human physiology systems. We apply this anthropomorphic approach to the interpretation of actual robot-arms for disabled people before to apply it in section 4 to a general analysis of the wheelchair, from its manual form to its advanced bipedal robotic form. Finally, we will try to emphasize a general interdependence principle peculiar to structural anthropomorphism whose a better understanding coul help for the future development of advanced technical devices for disabled people.

II. A SYSTEMIC APPROACH OF THE RELATIONSHIP BETWEEN DISABLED PEOPLE AND THEIR ENVIRONMENT

The disability is generally defined as a physical or a mental impairment. For example, in a legal point of view, the American with Disabilities Act (ADA) is based on the following definition of “handicapped individual” : “Any person who (A) has a physical or mental impairment which substantially limits one or more of such person’s major life activities, (B) has a record of such impairment, or (C) is regarded as having such an impairment”. However, as emphasized by M.T.Friedland [5], the “definition of disability has created many counterintuitive results in employment-related suits brought under the ADA by individuals with physical impairments” (page 172), due to the difficulty to rigorously specify the concept of “major life activity”. In her extensive paper, M.T.Friedland gives the following example: “[…] in McKay v. Toyota Motor Manufacturing, the plaintiff claimed that she was fired from her assembly line job because she developed carpal tunnel syndrome that kept her from performing her job without accomodation. The Sixth Circuit affirmed the dismissal of the case on summary judgment, finding that the plaintiff’s carpal tunnel syndrome did not substantially limit any major life activities and that the plaintiff therefore was ineligible to bring suit under the ADA” (page 172). This example highlights the complex relationship between the disabled and his/her environment. On the one hand, a disabled person is able to adapt his/herself to the environment built by and for non-disabled people until a certain limit which is not easy to determine. On the other hand, some authors have emphasized a fundamental distinction between disability and handicap : as written by A.C. Yearwood, “being disabled doesn’t mean being handicapped. You don’t have to be handicapped, which is a social term, because you have a disability, which is a limit in your physical capacity” [6]. According to A.C. Yearwood, “Characteristics of the built environment, rather than the degree of disability, determine whether or not a person is handicapped. A handicap occurs when a person encounters an

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B. Tondu and N. Bardou are with the LATTIS (Laboratoire Toulousain de Technologie et d’Ingénierie et des Systèmes), University of Toulouse, Campus de Rangueil, 31077 Toulouse, France (corresponding author to provide : bertrand.tondu@insa-toulouse.fr).

environmental barrier which prevents or inhibits activities of daily living" (page 299). Fig. 1 scheme synthesizes this double adaptation movement peculiar to the actual daily life of a disabled : his/her own limited ability of physiological adaptation to a given private or public environment and the means of environmental adaptation that he/she can expected. It is however important to remark that this adaptation of disabled to their environment has not always positive consequences. For example, older people with walking impairment may drink less fluid to reduce their urination frequency. The general role of technics face to the disability can be understood as the development of new means for a positive adaptation of disabled to their environment.

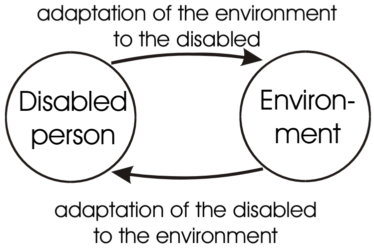


Fig. 1 Adaptation loop between disable people and their environment: on the one hand, the individual with impairment adapt his/herself to his/her environment, on the other hand, the environment can be partially adapted to a given disability.

In the case of a physical impairment, this adaptation can consequently combine three entities : the disabled individual, the technical device and the environment. Among these three items, the role of the technical device is so, as illustrated in Fig. 2, a motor and/or sensitive intermediary between the disabled and his/her environment.

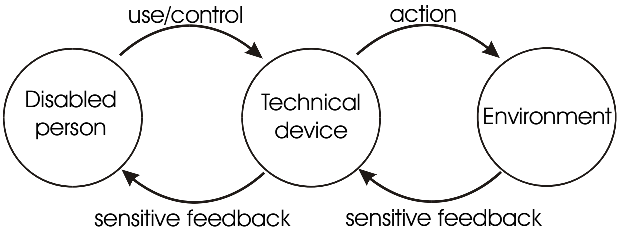


Fig. 2 The technical device as an intermediary between the disabled individual and his/her environment.

In accordance with Ernst Kapp's theory of organ projection, an assistive device for disabled people can appear to be some attempt to "extend" his/her body in order to give to him/her substitution means for being active in the envinronment. The blinder walking-stick is a good example of this approach : it is just a long stick that extends the arm blinder and which through its contact with the environment emits a sound-information in substitution to a missing visual information and to a tactile information that would be generated too late. Because any technical device for disabled people is aimed to serve as a subsitute for lost or impaired physiological functions, they are concerned by the anthropomohism question. This is to better understand this relationship between engineering for disable people and anthropomohism that we have tried to give a theoretical framework to a "technical anthropomorphism".

III. FUNCTIONAL AND STRUCTURAL ANTHROPOMORPHISM

In a technical point of view, anthropomorphism is generally understood as the act of giving a human form to something. In order to make more useful this large definition of anthropomorphism, the Carnegie Mellon university school of design [7], [8] has recently proposed to distinguish four kinds of anthropomorphic form :

- *A structural anthropomorphic form*, imitating the "construction and operation of the human body with a focus on its materiality", as provided by a jointed small-scale pose-able artists model;
- *A gestural anthropomorphic form*, imitating the "ways people communicate with and through the human body with a focus on human behavior", as provided by some computer screen mimicking a human-like behavior when an incorrect password is entered (window shaking, for example, on the Mac OS 10.2 login screen);
- *An anthropomorphic form of character*, imitating "the traits, roles or functions of people", as performed by certain perfume or beauty treatment bottles emphasizing some male or female character;
- *An aware anthropomorphic form*, imitating "the human capacity for thought, intentionality or inquiry", as provided by number of science-fiction robotized heroes.

According to us, this typology can help us to highlight two main ways in the development of anthropomorphic technical devices :

- a first way that could be called *functional way*, consisting in providing a human function independently of the structural form; this would correspond to the gestural and aware anthroporphic forms;
- a second way that could be called *structural way*, consisting in a more or less accurate imitation of the human body; this would correspond to the previously defined structural and character anthropomorphic forms.

We will see in section 4 how the actual technical development of robotic wheelchair can illustrate this hesitation between functional and structural ways.

A. Structural anthropomorphism of the human body based on systems physiology

In order to be able to rigorously analyze this double possibility on the path of the anthropomorphism, we propose to specify the structural anthropomorphism from a systemic approach of the human physiology derived from sixties system theoricists. Since the emergence of Wieners's cybernetic theory, the human physiology is often presented as founded on the concept of homeostasis considered as a fundamental equilibrium general principle of the human body. The influence of cybernetic theory to human physiology can also be seen in the definition of the usual eleven physiological systems characterizing a fundamental physiological function to be performed by related organs : the skeletal, muscular, nervous, circulatory, gastrointestinal, respiratory, urinary, immune, endocrine, integumentary, and reproductive systems. In accordance with Berthalanffy's general system notion, each of these physiological systems can be viewed as a set of elements jointed by imposed relationships. In the sixties, Mesarovic has proposed a mathematical interpretation of the systemic relationship from the set theory Cartesian product notion [9], [10]. Let us consider a family of sets X_1 ,…, X_n which, as said by Mesarovic, are the "system terms" and let us define the Cartesian product $X = X_1 \times X_2 \times .. \times X_n$. The explicit definition of a general system X_S is given [10] (page 371) :

" A general system is a subset of the Cartesian product X : $X_S \subset X$ " (1)

In a previous work [11] inspired by polish theoricists in biomechanism [12]-[13] we have proposed to apply this notation to the human skeletal system *SKEL* defined as a subset of the Cartesian product of the set of bones constituting the human skeleton, we call *BONE*, and the set of physiological joints as defined by human joint physiology, we call *JOINT* , as follows :

$$SKEL \subset BONE \times BONE \times JOINT \tag{2}$$

For example, the triplet (scapula, humerus, glenohumeral joint) is an element of SKEL. The complete specification of *SKEL* necessitates to specify all triplets belonging to it.

It is then possible to define an anthropomorphism of a given physiological system as a mapping from a real system X_S to a model system $X_S^M \subset X_1^M \times X_2^M \times .. \times X_n^M$ as follows :

$$\begin{array}{ccc} X_S & \rightarrow & X_S^M \\ \subset X_1 \times .. \times X_n & & \subset X_1^M \times .. \times X_n^M \\ x = (x_{S_1}, ..., x_{S_n}) & \rightarrow & x^M = (x_{S_1}^M, ..., x_{S_n}^M) \end{array} \tag{3}$$

where X_i^M is a model-set of X_i . The structural anthropomorphism of the skeletal system can be so defined from the following skeletal system model :

$$SKEL^M \subset BONE^M \times BONE^M \times JOINT^M \tag{4}$$

where $BONE^M$ and $JOINT^M$ are the model-sets of respectively *BONE* and *JOINT*. (see our reference [11] for details concerning these models).

This mathematical approach has, according to us, the great advantage of giving the possibility of a "measurement" of the anthropomorphism of a model system X_S^M in comparison with the actual system X_S , in the form of the ratio μ between the number of elements of the corresponding set supposed to be finite as follows :

$$\mu = Power(X_S^M) / Power(X_S) \tag{5}$$

However, in practive, the actual considered physiological system can be known only through the knowledge of a reference model, we will call X_S^{M-ref} , which is established in the framework of a given theory (see our paper [14] and references therein). Fig. 3 gives a representation of this reference model of the skeletal system that we will use in this paper.

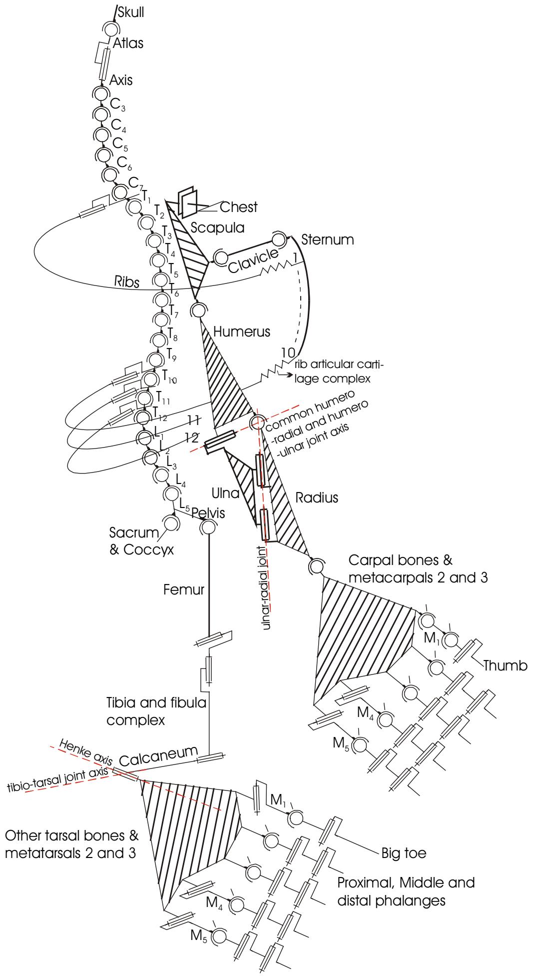


Fig. 3 Representation of the skeletal system model in which bones are represented by links and joints by kinematic symbols based on an interpretation of each physiological joint as a mechanical joint.

Taking into account this reference model notion, the modified anthropomorphism criterion results :

$$\mu = Power(X_S^M) / Power(X_S^{M-ref}) \tag{6}$$

We will apply in next paragraph this criterion to the musculoskeletal system. In the specific case of the skeletal system, this criterion can appear too global also (each physiological joint has the same importance independently of its number of d.o.f.). It can be asked if more specific criteria could be highlighted in order to compare the actual model and the reference model. The look for these criteria depends now on the system specificity. In the case of the skeletal system, one such criterion emerges, the mobility criterion, defined as the ratio of the numbers of degrees of freedom between the considered model and the reference one, so defined as follows:

$$\mu_{mobility} = Mobility(Skel^{M}) / Mobility(Skel^{M-ref}) \qquad (7)$$

where *Mobility* defines the number of degrees of freedom of the corresponding skeletal structure. Let us apply this criterion to the case of the MANUS robot, commercially called ARM (Assistive Robotic Manipulator) [15] shown in Fig. 4. MANUS is actually one of the most known and experimented robot-arm for disabled assistance [16], [17]; it can be used put on the ground or a table or, as shown in Fig. 4, mounted on a wheelchair. In accordance with robotics technology, MANUS is an “anthropomorphic-type” robot-arm with 6 d.o.f. (degrees of freedom). Its, as generally specified in Industrial Robotics, is computed without taking into account the gripper. In consequence, if we apply equation (7) criterion, we have to compare it with an upper limb reference model without hand model. The upper limb mobility without the hand, as it can be determined from Fig. 3 reference model, is generally estimated to 9 [14]. So we get :

$$\mu_{mobility\ \ MANUS} = 6/9 \approx 66\,\% \qquad (8)$$

which is relatively satisfactory. But this result does not fully express the expected ability of MANUS in a human-like manipulation task. To do that, we need to take into account the robot gripper which, at our knowledge, is always the same with only 1 d.o.f.. Considering a human hand mobility estimated to 23 d.o.f. (see Fig. 3 where the thumb has 5 d.o.f., the digits 2 and 3, each, 4 d.o.f. and the digits 4 and 5, each, 5 d.o.f.) the mobility criterion is now :

$$\mu_{mobility\ \ MANUS+gripper} = 7/32 \approx 22\,\% \qquad (9)$$

which is now much less satisfactory and can even be yet divided by two if we consider that the task illustrated in Fig. 4.a necessitates the use of the two hands to handle the bottle and in the same time to unscrew its cork. If we are well attentive to all details of the task shown on this picture, it can be asked if finally the robot, in this peculiar case, would be convenient for the disabled. Fig. 4.b illustrates an other possible task of the MANUS arm in a public envinronment : to pick up some commercial good in a store. The task seems easier to perform but once again it can be asked if the gripper is adapted to the picking up of a CD in a display as suggested by the picture.

(a)

(b)

Fig. 4 The MANUS robot mounted on a wheelchair in a typical task in private (a) or public (b) environment.

According to us, this example highlights the relevance of an anthropomorphic criterion to analyze more rigorously the possible performances of robotic devices engaged in complex assistive tasks for disabled people. We want now to show how this mathematical approach of the structural anthropomorphism can take into account a fundamental property of physiological systems : their interdependence.

B. Local and global anthropomorphism

The mentioned eleven fundamental physiological systems can be modeled separately as Fig. 3 illustrates it in the case of the skeletal system, but it is well known that they work in reality in close collaboration. This is to express this physiological dependence that Morecki, Ekiel and Fidelus have proposed a fundamental distinction between local and global anthropomorphism as illustrated in Fig. 5 : a local anthropomorphism is limited to a part of a given phsyiological system or to the full considered physiological system or even to some ones considered together; at the opposite, a global anthropomorphism considers the man as a whole.

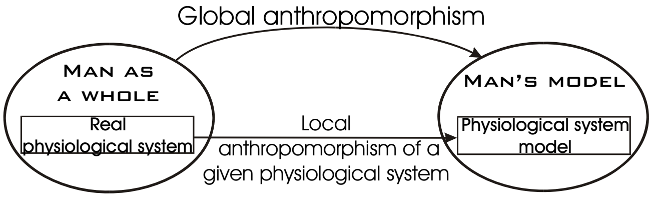


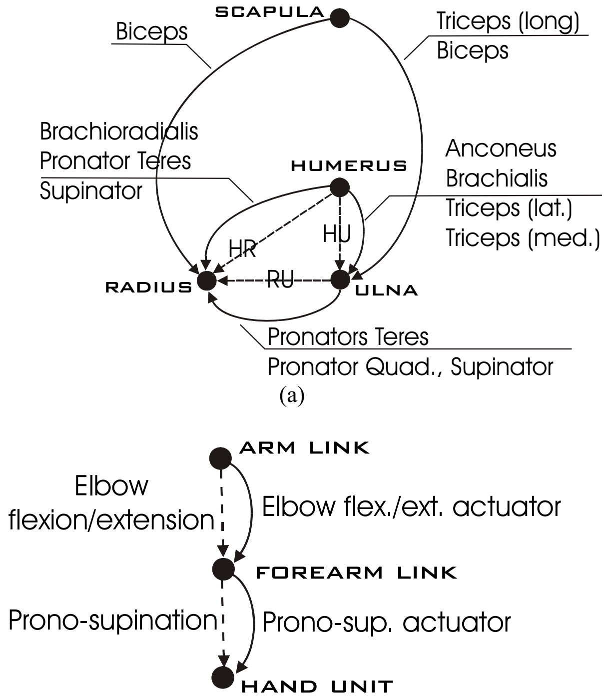
Fig. 5 Local and global anthropomorphism.

In fact, any anthropomorphism is a local anthropomorphism since no model exists of the living being considered as a whole. The interest of this distinction lies precisely in the assertion of this unavoidable “locality” whose effects can be difficult to estimate.

Let us illustrate this question in the case of a robot-arm for disable people. Up to now, we have limited our analysis to the alone mimetism of the skeletal system. What happens if we want to take into account the muscular system, not at the level of the muscle physiology but at the global level of its structure? The combination of the skeletal and muscular systems into a musculoskeletal system can be made by adding to the skeletal system the relations between bones and muscles. The new relational system *SKELMUS* results :

$$SKELMUS \subset BONE \times BONE \times JOINT \times MUSCLE \qquad (10)$$

where *MUSCLE* designates the set of skeleton muscles. Let us however note that it is necessary to add an element '*no direct joint*' to the set *JOINT* in order to consider the possibility of a link between bones by means of muscles independently of a given joint, as illustrated in Fig. 6.a : in this case, the muscle "short-circuits" a jointed chain. Due to the complexity of muscle attachment to bones, it is difficult to propose a simple and accurate schematic representation of the musculoskeletal system, as made for the skeletal system. Sagittal representation appears in this case well adapted, as illustrated in limited elbow joint musculoskeletal subsystem of Fig. 6.a : the concerned bones are represented by nodes, the acting muscles by full line links oriented from muscle origin to muscle insertion and joints by dotted arrows (*HU* is for humeral-ulnar joint, *HR* for humeral-radial joint and *RU* for radio-ulnar joint). This scheme highlights a specificity of the musculoskeletal system : its natural redundancy. In fact, the number of muscles motorizing a joint is generally greater than the number of elementary motions in abduction/adduction, flexion/extension and external/internal rotation peculiar to the joint. For example, it is generally considered that five muscle can participate to the elbow flexion-extension – four for the flexion and one for the extension.



(a)

(b)

Fig. 6 Saggital diagram of the human elbow musculo-skeletal subsystem (a) compared to a corresponding diagram established for a classic 6R robot-arm like MANUS (b).

In comparison, an anthropomorphic industrial robot motorized by classic actuators, whose MANUS is a typical example, has a corresponding saggital diagram much more simple since each joint is actuated by only one actuator, as illustrated in Fig. 6.b : the arm, forearm and hand unit links are jointed by one revolute joint and one actuator. If we apply the general equation (6) anthropomorphic criterion to this special case, we get[1] :

$$\mu_{MANUS\ elbow\ with\ actuators} = 2/13 \approx 15\,\% \qquad (11)$$

In an unpublished work [18] we have attempted to establish a complete saggital diagram of the human upper limb based on biomechanics studies of the upper limb. In particular, from Jazrawi et alia' proposed scheme of origins and insertions of muscles of the upper limb [19] (page 351) and from indications given by Kapandji [20], we have got the following estimation of the power of the reference model of the upper limb musculoskeletal subsystem $SKELMUS^{M-ref}_{UpperLimb}$:

$$Power\,(SKELMUS^{\,M-ref}_{\,UpperLimb}) = 61 \qquad (12)$$

If we now apply the general criterion of equation (6) to the case of the MANUS robot (6 joints + 6 actuators and 1 d.o.f. gripper), we get :

$$\mu_{MANUS\,+\,gripper\ with\ actuators} = 7/61 \approx 11\,\% \qquad (13)$$

This estimation as the one restricted to the elbow musculoskeletal subsystem lead so to emphasize the limited structural anthropomorphism of actual robot arms aimed to assist disabled people in their daily life. In opposite to industrial robotics, it is generally not possible to adapt the environment to the robot. In consequence, it seems to be obvious that a majority of daily manipulation tasks thought for the human dexterity are in fact impossible to be performed by a classic 6R – or even 7R – robot with a one – or even 2 or 3 – d.o.f. gripper. However, it is important to remark that, even if an artificial muscle was available [21], a complete mimicking of the upper limb musculoskeletal system would lead to a delicate control problem. How to control the about 60 artificial muscle of an anthropomorphic upper limb ? What kind of interface to propose to the disabled to make possible this control and efficient the resulting task in his/her narrow environment ? The lack of both a clear model of the nervous musculoskeletal system and a clear knowledge of motor control seem to have led to actually privilege some balance between a relatively poor mimetism of the upperlimb musculoskeletal system adapted to basic manipulation tasks and a control device adapted to the user. In the case of disabled people, the joystick is often privileged. It can be considered as a non-anthropomorphic interface whose use implies for the performance of tasks defined in Cartesian space the call to an inverse kinematic modelling as Industrial

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[1] The power of each relational model can easily be computed from the reading of the corresponding saggital diagram : since to any considered joint is associated at least one muscle, the power of any system-model included into $BONE \times BONE \times JOINT \times MUSCLE$ is equal to the sum of all muscles (or muscle portions) indicated by an arrow from a bone to an other one : in Fig. 6.a, the full line arrows add up to a number of 13 muscles when they are only 2 in Fig. 6.b scheme.

Robotics highlighted the relevance. But it is also possible to imagine anthropomorphic interfaces able to capture the motor orders at their nervous origins. The control by "thought" of recent prosthetic arms [22], [23] or wheelchairs [24] is defined in accordance with this principle. Fig. 7, for example, shows the last 8 d.o.f. version of the well known Bionic Arm developped at the Rehabilitation Institute of Chicago (RIC) since about 2000 : each degree of freedom is naturally controlled by Targeted Muscle Reinnervation (TMR) that involves the transfer of residual nerves from an amputated limb to unused muscle regions in appropriate proximity to the injury; in the case of the Bionic Arm, the nerves are transferred from the soulder to the pectoral area where are located the control electrodes.

Fig. 7 Eight Degrees of Freedom Bionic Arm of the RIC controlled by "thought" (see text).

Although yet limited by the difficulty to accurately capture enough nervous orders in correlation with corresponding actuators to mimick the motor control subtlety, these attempts highlights the great hope of this approach : in opposite with a humanoid robot whose anthropomorphism in theory is supposed to be global, the "perfect" robot for disabled people could appear as the anthropomorphic "complementary" of the disabled to be directly interfaced with his/her healthy physiological systems or subsystems, as illustrated in Fig. 8. For example, in the case of the RIC's Bionic Arm, the Fig. 7's Proto 1, despite what can be thought when we see the picture, has a hand mobility very limited but the goal of the Revolutionizing Prosthetics 2009 (RP 2009) team is to give to a second prototype Proto 2 more than 25 d.o.f. with a more complex jointed hand, which is close to the natural upper limb mobility as it can be estimated from Fig. 3's skeletal reference model.

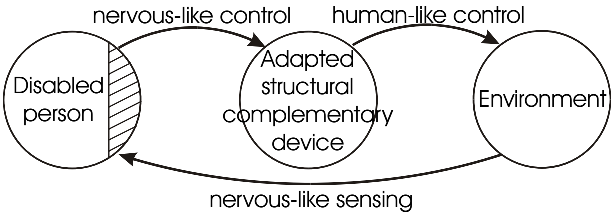


Fig. 8 Anthropomorphic approach combining a human-like musculoskeletal mechanical structure with a control device interfaced to the natural nervous system (the hachured portion of the "disabled person" entity).

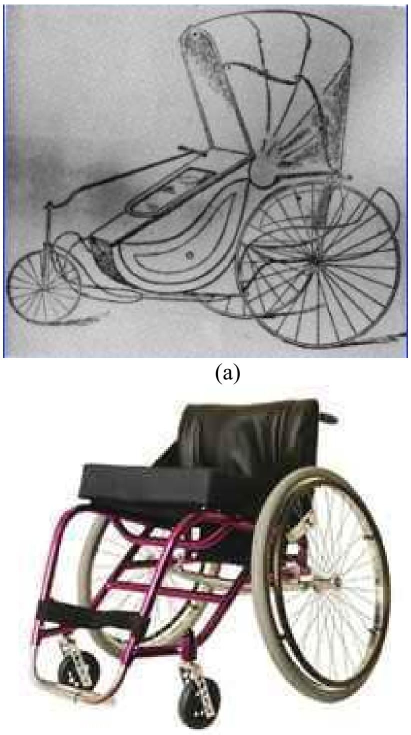
We have essentially illustrated our concepts of structural anthropomorphism in the case of a robot-arm for disabled people. Let us now try to show how our general analysis of anthropomorphism could help to better understand the technical evolution of a fundamental device for physically disabled people : the wheelchair.

IV. CASE STUDY : FROM THE FUNCTIONAL ANTHROPOMORPHISM OF THE WHEELCHAIR TO ITS EXPERIMENTAL STRUCTURAL ANTHROPOMORPHIC ROBOT-FORM.

The wheelchair is an example particularly important in the understanding of technical devices for disable people due to its long history and its large public. It is surprising to verify that its global form – a chair mounted on a frame with two large rear wheels and one or two small front wheels – has relatively little changed since the invention of the "bath" chair, illustrated in Fig. 9.a, by John Dawson in 1783 [25].

A. The manual wheelchair as a tool

In its "manual form", it has been seldom remarked that the wheelchair can be technically spoken assimilated to a non-motorized tool manipulated by the two hands of the disabled in such a joint way that the wheelchair and his/her driver show high mobility abilities. Its recent evolution towards a "performant" version adapted to "wheelchair sports" is similar in some manner to the technical evolution of any professional tool or sportive equipment which takes beneficit from new available materials to increase its lightweight, versatility and endurance, as illustrated with the recent "Camber" wheelchair shown in Fig. 9.b. In comparison with the historical "bath" chair, the general "form" is kept but in its actual manual use the steering stick disapears and this is the disabled him/herself which moves and drives the wheelchairs by means of his/her hands directly acting on the motor wheels. How to explain however the long-life of this general form since more than 200 years ?


(a)

(b)

Fig. 9 Technical evolution of the wheelchair from the John Dawson's "bath" chair to the "Camber" (see text).

B. The subtle functional anthropomorphism of the manual wheelchair

The wheelchair like any device derived from the wheel invention is typically a non-anthropomorphic device in the structural sense defined in section 3 since the wheel is not inspired by a organic form. However, a wheelchair is not like a car driven by means of a steering wheel; contrary to a car, a wheelchair controlled by skilled hands seems to be able to approach a fundamental human mobility property : its holonomy i.e. the ability to take in each location any desired displacement direction. This is this ability which can explain the recent development of so amazing wheelchair sports like basketball and tennis which require quick direction changes in a limited area. We think that this human-like holonomy exhibited by some disabled people driven their wheelchair is a consequence of the dexterity and power of their healthy upper limbs acting on a mechanical device particularly well adapted to turn "short" thanks to its small front wheels and whose global manoeuvrability has been yet increased by the use of new light materials. Stability, increased by wheels camber, and manoeuvrability make the recent manual wheelchair version a purely mechanical device surprisingly able to restore a stable and almost human-like holonomic walking, through a non-structural anthropomorphic way. The major limitation on this non-structural anthropomorphism is naturally the difficulty and often the impossibility to jump over obstacles. It is however important to remark that this limitation can be compensated by an adequate environment anthropomorphism, as illustrated by the "kneeling bus" (cited in [8]) whose function is, by means of hydraulic mechanism, to lower the front side of the bus closest to the curb to allow the entrance of the wheelchair into the bus, as shown in Fig. 10 right hand side photography. This adaptation of the environment to the assistive device can be considered as complementary to the natural one of the disabled individual to his/her environment emphasized in section 2, as we illustrate it in Fig. 10.

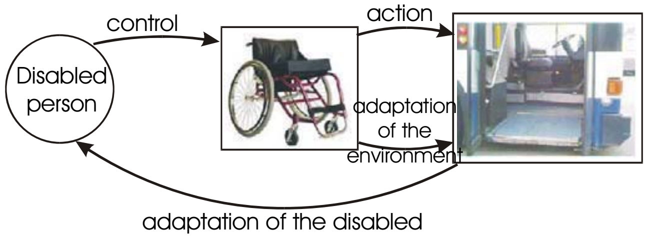


Fig. 10 Example of a "anthropomorphic" adaptation – the "kneeling bus " (from [8]) – of the environment to the wheelchair considered as a non-anthropomorphic structural form (see text).

We think that this analysis can help to explain why the purely functional anthropomorphism of the manual wheelchair keeps the best technical solution to the mobility disability of young active pareplegic people. In its lighter version, the manual wheelchair can appear like a kind of non human-like exoskeleton. However this approach is not suitable for aged paraplegic people or for more severe disabled people whose the vigorous use of upperlimbs for giving the needed power to the wheelchair is not possible. Robotics has given new possibilities to the development of motorized wheelchairs.

C. The difficult challenge of robotized wheelchairs

In comparison with the Fig. 9.b Camber wheelchair, the MAid (Mobility Aid for elderly and disabled people) [26] shown Fig. 11 can appear at first sight little human-friendly! In fact the users of the two wheelchairs are different : Maid has been designed "to support and transport people with limited motion skills such as elderly people affected by paraplegia, multiple sclerosis, poliomyelitis, muscular dystrophy, and other debilitating" [26] (page 38).

Fig. 11 MAid robot (from [26]) : typical example of a robotized wheelchair whose sensors and computer equipment make it similar in some extent to a mobile robot.

The more severely disability of the muscular system implies an increasing of the mobility functional anthropomorphism, in particular by giving to the robot the ability to navigate in narrow, cluttered envinronment, in the one hand, through wide, crowded areas in the other hand. Due to the interdependence of physiological systems, an obstacle avoidance task performed by a mobile robot put into work several sub-functions peculiar to the skeletal and muscular systems but also to the nervous system and to the integumentary system as a sensitive interface with the outside world – without mentioning the energetic autonomy problem. The robot designer is so face to a complex integration problem whose proposed solutions have generally as a consequence a loss of compacity and a weight increasing due to the weight of actuators and their mechanical transmission, of the battery and the actual technological lack of low cost accurate and miniaturized sensors. The intelligent wheelchair can consequently become a cumbersome and heavy machine without one of the fundamental property of the historical wheelchair emphasized in paragraph 4.2, the quasi-holonomy of its displacements due notably to the need to increase for mechanical reasons the diameter of front wheels (see to compare them the figures 9.b and 11). As highlighted by R. Simpson in his recent literature review on smart wheelchairs [27], "[...] very few smart wheelchair researchers have involved people with disabilities in their evaluation activities" (page 432). And when they do it, "some wheelchair users do not show any immediate improvement in navigation skills" (page 432). According to Simpson, "this could be because the smart wheelchair does not work very well or the wheelchair user was already proficient that little improvement was possible". Let us try to interpret this relative failure in our proposed framework. In our anthropomorphic perspective, actual intelligent wheelchair prototypes result from a balanced functional anthropomorphism putting into work several physiological functions : mobility, navigation skills, tactile perception, vision, ... ; and contrary to the couple 'disabled-manual wheelchair', the couple 'disabled-smart wheelchair' can become "discordant" due to an attempt to increase the functional anthropomorphism of the machine without taking into account the disabled adaptation processes. Furthermore, because the resulting device is generally obtained to the detriment of the compacity and lightness, the adaptation to the environment can be more difficult than in the case of the manual wheelchair, particularly for security reasons and carriage difficulties. As illustrated in Fig. 12 where three recent intelligent wheelchairs are shown – the CWA (Collaborative Wheelchair Assistant) [28] to be set on a classic manual wheelchair, the SENA robotic wheelchair [29] and the previously mentioned Maid robot – from the least complex (at the top) to the most complex (at the bottom), it is clear that more technology for autonomy is integrated more the intelligent wheelchair looks like a mobile robot imposing its bulkiness and its weight to its environment.

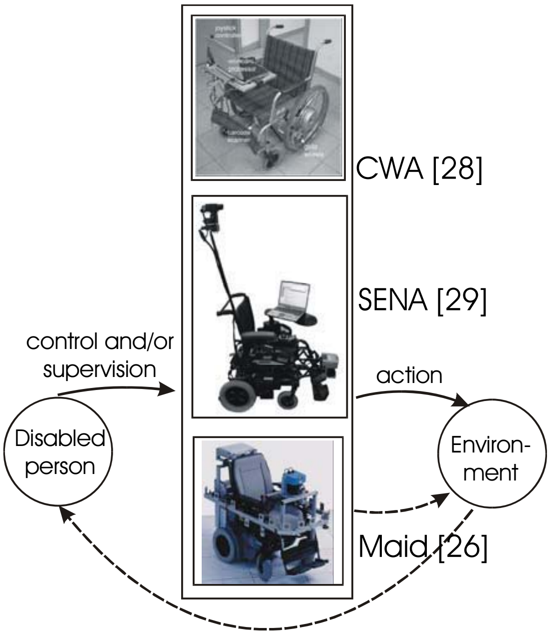


Fig. 12 Comparison of some recent robotized wheelchairs : more the robotized wheelchair is technically complex, more its adaptation can be difficult : the 'adapatation' arrows in dotted line emphasize this possible deterioration of the loop adaptation defined in Fig. 1.

Face to this risk to transform the intelligent wheelchair into an autonomous mobile robot too little adapted to the diversity of private and public human-made environment, it has been recently envisaged to abandon the functional anthropomorphic way for a structural anthropomorphic way which consists in the case of the wheel chair to imagine a 'bipedal form' of the wheelchair, as illustrated in Fig. 13. This choice is naturally motivated by the natural adaptation of a legged robot to our architectural environment : the left hand side prototype [30] is composed of telescopic legs which makes it a parallel-type robot when the right hand side prototype [31] is composed of human-like legs.

Let us try to apply our mobility criterion given in equation (7). Because human walking can be modelled in a very satisfactory manner by considering all foot digits as one link jointed at the tarsal bones, the mobility of the lower limb according to Fig. 3 reference model is estimated to 8 as follows : 3 d.o.f. for the tip, 2 d.o.f. for the knee, 2 d.o.f. for the ankle and one last d.o.f. in flexion/extension between the foot "immobile unit" and the set of foot digits. In consequence, the anthropomorphism of a 6 d.o.f. robot-leg can be estimated as :

$$\mu_{mobility\ 6\ d.o.f.\ robot\text{-}leg} = 6/8 \approx 75\,\% \qquad (14)$$

much more higher than the one computed for the MANUS robot-arm. However, this result must be considered with prudence because the human-like autonomy bipedal walking introduces a new problem : the global stability of the robot with his/her passenger. Humanoid robotics has recently proposed stability solutions derived from great mechanics principles through notably the Zero Moment Point concept

[32], [33] but the secure adaptation of a bipedal robot to a changing floor is yet to be established, due to the difficulty to mimick the complex association peculiar to human walking between the foot placement and the jointed movement of the vertebral column.

(a) (b)

Fig. 13 Examples of biped walking wheelchairs with (a) parallel chain-type legs (from [30]) or (b) serial chain-type legs (from [31]).

This example of a posible biped "wheelchair" illustrates according to us a fundamental principle of any structural anthropomorphism : any initial and partial anthropomorphism induces peculiar problems whose an "optimal" solution, but actually technically difficult to be mimicked, seems have been developed by the nature itself through the physiological systems and sub-systems interdependency. If we limit our analysis to the alone skeletal system, we have already shown the effect of the choice of an industrial robotics-type gripper on the anthropomorphic measure of a robot-arm for disabled people. In the case of a bipedal robot, this is the absence of a jointed vertebral column which can limit the efficiency of the robot due to its role in the dynamic equilibrium during walking.

To conclude this case study on the wheelchair, a dilemma appears: either the functional way is adopted with the risk to make the robot inadapted to many human-built environment, or the structural anthropomorphic way is adopted with the risk of designing a device to difficult to be controlled. In the one as in the other case, its is clear, as suggested by several studies, that some optimal "partitioning" can be determined between the user and the expected assistive tasks, as discussed in conclusion. For example, in the case of the "bipedal robot-[wheel]chair", the user could play an active role in the walking supervision.

V. CONCLUSION

We have proposed in this paper to distinguish two main ways for the anthropomorphism of technical devices : a functional way which mimicks a function without mimicking the human physiology and a structural way which aims to get the desired human function through some technical replica of the human physiology.

We think that technical devices for disable people can choose one or the other way. The first one permits to avoid the typical human body complexity that we have tried to express as a systemic interdepency between the multiple physiological systems. The wheelchair is undoubtly one of the most known assistive technology. However more the disability is severe, more complementary technical devices must be integrated into a machine which can become badly adapted to the human-made public environment. The second way seems so to be necessary as a future challenge for giving a larger autonomy to severe physically disabled people by means, in particular, of anthropomorphic arms and/or legs. A peculiar difficulty occurs, however, whose bringing out constitutes the originality of our work : **any partial or local structural anthropomorphism generates new anthropomorphic needs due to the physiological systems interdependency**. For example, the robot-arm as an assistive device needs a human-like hand to be fully adapted to its envinronment and some analogical technical device of the tegumentary system to avoid any domage caused by the robot. Other case : the attempt of a completely renewed wheelchair in the form of a bipedal autonomous robot induces the new question of the global robot stability helped in the human body by the jointed vertebral column.

As already suggested by researchers in intelligent systems [34] for disable people, such difficulties can be partially solved by taking benefecit of the disable abilities. The "Camber" wheelchair for sports gives us a good example of adaptation of the disable individual to his/her assistive device: the lost holomic mobility peculiar to human walking is almost recovered by a close cooperation between the machine and the disabled person transfering in some way its always available upper body ability to the machine. We think that it is this kind of narrow cooperation between a human-like robot and the disabled which could help to control the systemic complexity of a given anthropomorphic structure. In pratice, this specific human-machine expected cooperation would be considered since the early design of the anthropomorphic robotic device, in order to specify the optimal task apportioning between the robot and the disabled. A general scheme 'High level control by the disabled-Low level control by the robot' seems to be particularly applicable. Fig. 14 integrates to the adaptation loop initially proposed in Fig. 1 scheme this double low and and high level feedback : the high level control corresponds to the nervous system too yet difficult to be technically mimicked, and the low level control corresponds to the , skeletal, muscular and integumentary "relational" systems

However to be relevant, as mentioned for example in the case of the hand control, and beyond technical problems linked to the bio-mimetism of human actuators and sensors, a major problem must be solved: the specification of an efficient interface between our upper level motor consciousness and the lower level inconscious automatic motor abilities. A better knowledge of motor synergies resulting of the natural learning motor processes could be an help for this research.

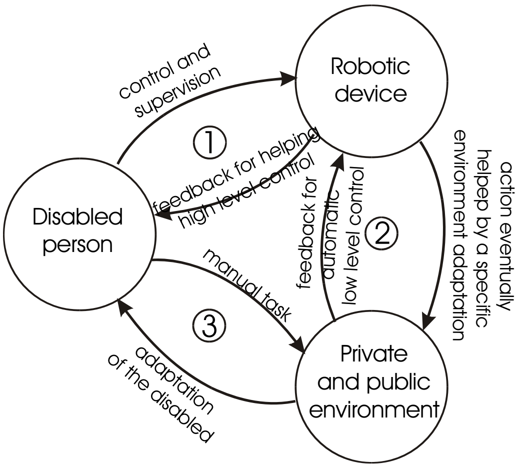


Fig. 14 Triple feedback general scheme of the relationships between the disabled person, his/her robotic device and his/her environment : the loop ① corresponds to the human in the robot high level control loop, the loop ② corresponds to the automatic robot low level control and the loop ③ corresponds to the manual feedback based on the disabled abilities.

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