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Comparative Analysis of Artificial Hands

The Need for Reporting and Test Standards

Carmel Ellul and Michael A. Saliba, *Member, IEEE*

***Abstract*—Comparative analysis is for several reasons an important aspect of research. In robotic hands, such an exercise may become very difficult or even unworkable due to various reasons. This paper is emphasizing that, in addition to their complex nature, continuous technological advancements, and other reasons found in the literature, the approach to testing and reporting is one of the sources of this problem. The level of reporting of common, artificial hand characteristics, as encountered in a small but varied sample of publications on artificial hands, has been analyzed and the findings are presented. A fresh attempt to highlight the necessity of an appropriate verification process and the benefits artificial hand research stands to gain through the implementation of a standardized test and report system, despite different project goals and fields of application, is carried out. Finally, a general discussion and some practical proposals regarding known and potential standard performance indicators are presented.**

Keywords-robotic hands; hand prostheses; benchmarking; testing; reporting; standardization, performance indicators

I. Introduction

Throughout the past years, many fascinating end-effectors and artificial hand projects have been presented, mainly through research publications. The declared goals, field of application, and final purpose of the developments are varied, with each often having different performance requirements. Consequently, diverse design philosophies that result in specific outcomes are adopted.

Variety inevitably leads to the comparison of the multitudes of achievements reported. Whether for research, educational or commercial purposes, it is natural and also useful to first compare the available solutions and respective performances, before proceeding with new research and development strategies, or before procuring a commercially available device. In the case of robotic hands, an evaluation and comparison exercise (that typically due to availability and cost is carried out without the hardware itself), can be rather difficult. This difficulty may arise not only because of the difference in individual project goals [1] and related fields of application [2], but also due to the level and nature of reporting made available.

This paper is highlighting the need for a standardized report and test system that provides, through a minimum set of commonly agreed upon and measurable characteristics, a useful information base for any build-stage of a specific device. Such uniform reporting need not replace but complement the existing publications that remain important in providing the detail behind the achievements.

In the following sections, the background and findings leading to this identified need, the reasoning behind its relevance, and its potential validity despite different project goals, will be presented together with a discussion and some proposals about existing and potential indicators, and test procedures.

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Carmel Ellul and Michael A. Saliba are with the Robotics and Industrial Automation Laboratory (RIAL), Department of Industrial and Manufacturing Engineering, University of Malta, MSD 2080 Malta (corresponding author's phone: +356 2340 2924; fax: +356 2134 3577; e-mail: michael.saliba@um.edu.mt).

II. Background

A. Applications, Classifications, and Project Emphasis

Robotic end-effector and hand projects are normally categorized according to the intended field of application as follows: those research oriented end-effectors for the study of grasping and manipulation e.g. [3], [4]; devices developed for increased flexibility in the manufacturing environment e.g. [5], [6]; end-effectors for space exploration e.g. [7], [8] and other hazardous environments; hands for humanoid and service robots e.g. [9], [10], and; artificial prosthetic hands for amputees e.g. [11], [12].

In [1], classifications that physically describe the end product have been outlined and in some cases augmented through quantification proposals. These include: anthropomorphism (with respect to the human hand); level of structural integration -- comprising self-contained end effectors that are designed to function independently of any carrying arm e.g. [4], [5], [7], [9], [11]-[14] and, those that similarly to the human hand include a necessary forearm e.g. [8], [10], [15]-[17] or other setup e.g. [3], [18] to remotely locate the actuators, and; structural design concept -- divided into exo-skeletal types e.g. [3]-[5], [7], [8], [11], [13]-[15], [18], where components are hosted inside articulated, rigid, hollow links and, endo-skeletal types e.g. [9], [12], [16], [17], where similar to the natural hand, components and optional soft external layers are positioned around an internal, articulated, skeletal framework.

On examining the details of each project, it can be observed that often the emphasis is placed on specific features such as the design and implementation of actuator and transmission technologies; sensorial capabilities and technologies, or; control strategies.

B. Literature Findings

Although project goals are varied and their requirements may seem to be far apart (e.g. a research hand has different requirements than a prosthesis that is developed to be light, wearable, and simply controlled by the amputee), a common base that defines an artificial hand does exist (see e.g. [1]). In general any artificial hand may be considered to be composed of: a mechanical framework; a kinematic configuration; an actuation and where necessary a transmission system; a sensory system; a control system; wiring; an interface to the surrounding environment such as an outer shell, contact pads and/or a covering skin, and; a power supply. The sensory system, contact pads, and covering skin could be optionally implemented. Characteristics such as mass, size, number of independent and dependent degrees of freedom (DOFs), speed, grasping and manipulation capabilities, etc., are used to outline their specific performance.

Notwithstanding this apparent commonality, a literature analysis of some basic characteristics revealed that the reporting made available in connection with artificial hand development is not uniform and at times information is missing.

Table 1 shows a summary of the analysis carried out to the best of our knowledge on fifteen selected publications. The papers chosen, [3]-[5] and [7]-[18], are just some examples of the available developments and, as described in Subsection II-A, represent sufficiently varied projects. The numbers listed in the rows of the table indicate the number of publications that tackled the specific characteristic – e.g. the mass of the hand, was reported in nine of the fifteen papers (9/15), whereas in the remaining six (6/15), it was not. As can be observed, incomplete reporting (**INC**), not clearly reported (**NC**) and, not reported (**NR**) is spread more or less across the whole sample of characteristics. In some cases, the information classified as reported (**R**) represents the presence of reasonable information rather than information according to an agreed standard.

While reiterating the validity of all contributions, it has to be observed that a direct and fact-based comparison between the hands using only the available information cannot be carried out. For example, where provided, both the grasping and finger-tip forces are reported under different or unspecified circumstances and even though these have here been classified as reported, a direct comparison is still not possible.

With regard to information voids, although additional insight might be obtained through other publications related to the same project, data cannot be reliably collated without the availability of a discernable design status (i.e. a hand version). A distinct design status is traceable in only some of the reviewed publications. However, it is not generally known whether the specific versions are subject to a 'design freeze' or if changes within the same version are permitted.

TABLE I.
SUMMARY OF THE LEVEL OF REPORTING OF COMMON ARTIFICIAL HAND CHARACTERISTICS IN SELECTED LITERATURE

Characteristic	R	INC	NC	NR
Mass (of the Hand)	9/15			6/15
Size / Volume (of the Hand)	2/15	4/15	5/15[a]	4/15
Kinematics	11/15[b]	2/15	2/15	
Independently controlled DOFs	12/15[c]		2/15	1/15
Range of Motion	6/15	3/15	4/15	2/15
Joint Speed	3/15	3/15[d]	5/15[e]	4/15
Grasping Forces	4/15			11/15
Finger-tip Forces	7/15			8/15
Resolution, Accuracy, Repeatability				15/15[f]
Reliability		7/15[g]		8/15
Noise (dBA)	1/15	1/15		13/15
Working Environment	2/15	1/15	1/15	11/15
Hand Version	6/15	2/15[h]		7/15

R: reported ***INC: incomplete***

NC: not clear ***NR: not reported***

a. four publications associate the size with that of the human counterpart without quantification.
b. five publications provide also a kinematic layout or similar.
c. potentially independently controlled DOFs.
d. time for a specific free motion (e.g. from fully open to closed).
e. reported step and/or frequency response and/or bandwidth.
f: five publications report sensor and/or motor encoder resolution.
g: discussed to some extent at hand and/or component level.
h: indicate that the prototype is the first without further details.

The issues just raised are not limited to artificial hands, but, from what is reported in [19], are common to robotics in general. The lack of information, the difficulties in comparing and, the need for better reporting and "good experimental practice", are also there highlighted. A web hub [20] for benchmarking, objective performance evaluation, and good experimental methodology in robotics was set up by the European Robotics Research Network of Excellence, Special Interest Group on Good Experimental Methodology and Benchmarking (EURON GEM SIG).

III. STANDARDIZED REPORTING SYSTEM

A. Reasoning Leading to the Identified Need

Many everyday life systems and processes include feedback loops. Activities involve either the conscious or the unconscious/automatic status assessment and the adjustment of inputs as necessary to achieve the desired targets. A walking person utilizes his senses together with his knowledge, to assess the current position and remaining distance to the intended destination. An electric kettle will automatically switch off as soon as the water starts to boil. Without this closed loop control, the walking person would probably miss his destination, and the kettle would keep on heating the water until no useful content remained and, damage to the hardware itself occurs.

The establishment of a closed loop feedback system is therefore often necessary and inevitable to reach set objectives. In the context of robotic hands, the “Balance in Approach” described in [3], that addresses the identification and management of realistic goals, remains a valid consideration that is observed to be thoroughly pursued throughout the literature.

A fact-based method of assessing goals must include suitable and measurable indicators. Hence, the identification, testing, and reporting of adequate and shareable indicators is very important. Such quantifiable indicators may not only help to verify the effectiveness of the efforts made, but would also outline any gap between the desirable objectives and achieved results.

Desirable objectives may have a defined value, such as for example ‘a hand mass of less than 600 grams’ or a more universal nature as for example ‘as low a hand mass as possible’. The difference is that in the former approach, success would have been achieved when the self-set or market driven constraint is fulfilled, whereas in the latter, questions about more stringent objectives, better results and, the comparison with other achievements would be automatically raised.

This comparison automatically defines a characteristic-related yardstick on which both objectives and achievements can be positioned. Such a yardstick would still enable a reasonable “balance in approach” to take place, but additionally, if a wide enough scale that encompasses the final application is tolerated, it could become an important agent that compels the drive towards further innovation and improvement. Considering again the mass, any hand for almost any application will result to be more efficient and desirable if it is intrinsically lighter.

B. *Universal Yardsticks*

Fiction has already imagined the technological mimicking of humans and the artificial replication of their limbs [21].

In the robotics community, an ideal configuration for an anthropomorphic, dexterous, robotic hand possessing reasonable performance, and where all components are integrated into the volume of the hand and wrist, has already been envisaged in [3]. More recently, the “ideal hand”, prosthetic hands that are “able to grasp and manipulate”, the “ultimate” cybernetic hand and, “the dream of reproducing the human hand capabilities” have been given consideration in [11] and [15].

Although such an ideal configuration has not been matched ([3], [11], [15], and others), many development efforts, especially through miniaturization, seem to be heeding our imagination. Hence, it should be reasonable to consider ‘yardsticks’ with limits that accommodate objectives in a broader sense rather than the current achievable goals. Given that an ideal hand has been imagined and is desirable, then such yardsticks should by default go beyond the specific field of application and act as one of the catalysts that drives efforts towards the ideal configuration.

Advanced prosthetic hands may also be considered proper robotic devices [22]. In [15], where the hand prosthesis can already generate a large set of different grasps required for activities of daily living, the increase in the number of DOFs is contemplated as part of the future improvements. During a state of the art review reported in the same paper, the application of robotic knowledge to improve important components of prosthetic hands has been acknowledged. Further, a list of characteristics for the natural hand and a comparison with the respective performance of the “CyberHand” is included. The relevance of the comparative exercise, in this case to analyze “technology tradeoffs among different biomechatronic components” is also highlighted. These considerations suggest that prosthetic hands can be evaluated to some extent using many of the same yardsticks as other robot hands, and additionally, that certain aspects of the human hand can be used to guide the definition of these yardsticks.

The human hand itself has several of its actuators stowed in the forearm and from this aspect the ideal device envisaged in [3] already has more stringent requirements than the natural organ that it is trying to imitate. Effectively, this type of ideal end-effector, besides being required for real and immediate needs such as artificial prosthesis suiting amputees even with wrist disarticulation, or of tele-operation in compact situations, would indeed be desirable for many other applications. In [3], where the artificial hand was built for research purposes, a “remotizing system” was required to conduct the tendons from the actuation package to the robotic hand, permitting the former to remain static, while the latter is positioned in space by a robot arm.

C. *Shareable Indicators*

If comparisons between robotic hands are to take place, then a minimum set of indicators, have to be common. From the increasing variety of content encountered as more literature is reviewed (examples of which are highlighted below), it seems necessary that agreement should be reached for these indicators to become shareable.

In [2] a universal testing rig to determine the holding forces of different artificial and natural hands according to European Standard EN 12523, which deals with the requirements and test methods for external limb prostheses and orthoses [23], was built. In their work, the authors commented that although the above test is intended for prostheses and orthoses, the evaluated criteria would be also important for robot hands designed for human interaction. It was also noted that: “the analysis of forces applied during grasping is very significant for all kinds of artificial hands”; data regarding the holding forces for robotic and human hands are very sparse in the literature, and; due to the lack of data according to accepted standards, the measurements carried out cannot be directly compared with those of other robotic hand research groups.

In [11] the generalized grasping force of the prosthesis when performing power grasps of cylinders with three different outer diameters (52, 67, and 80 millimeter), was estimated through experimental tests. Tests at different levels of motor current supply (one dc motor actuates all the fingers), were carried out with the “SPRING” hand in a pronosupinated position and with the axes of the three fingers perpendicular to the cylinder main axis. The power drawn during the performances was also noted.

In [14] the fingertip forces were designed so that the thumb, index, and middle fingers can apply 10, 5, and 5 Newton respectively during a thumb and two-finger precision grasp of a cylinder with 25 millimeter outer diameter. In [16] the maximum tip force that the index finger can apply perpendicular to its longitudinal axis was measured.

In [3] it is reported that the tendon configuration has been subject to life tests, and that the reliability of the whole system, which is aimed at long-term operation, was "exhaustively evaluated". In [17], the compliant joint construction showed no failures after thousands of working cycles, and was deemed to have a good reliability.

In [8] the space compatibility of the "Robonaut" hand materials and components is discussed, whereas the suitability in wet conditions of the hand developed in [10] is somewhat demonstrated through a picture of the hand under water.

In [4] and more formally later in [24], a quantitative, thumb opposability performance index has been defined.

The above examples show that although authors make genuine efforts to quantify the performance of their devices, they are doing so in the absence of mutually agreed standards.

IV. Discussion and Some Proposals

A. *A Standardised Report and Test System*

The encountered state of affairs need not be the case. A standard report system that includes a minimum set of shareable indicators that address common characteristics of artificial hands, would tackle the encountered information voids and any related misinterpretation. This is also applicable to those indicators that can be affected by changes in the state of the hand (e.g. joint positions). Considering the grasping forces for example, the situation could be improved through the identification of a minimum set of shareable grasping postures and respective circumstantial conditions. If one of the minimum postures identified is a cylindrical power grasp, then the physical properties of any cylinders to be utilized need to be defined.

Additionally, theoretical and experimental results need to be clearly distinguished. In the publications reviewed, it is not always clear whether the reported values are coming from experiments or from theoretical models. Where prototypes are built, it is best to report clearly the experimental results. While results coming from theoretical studies would still allow a reasonable evaluation and direct comparison to take place, those originating from standard test procedures using properly calibrated equipment would make such processes fact based. Hence, the need to define and implement standard procedures within a standardized reporting system is further emphasized.

The above reasoning is applicable to several other artificial hand related characteristics. For example in the case of mass, it could be perhaps more practical to weigh the complete prototype and associated modules on a calibrated scale rather than obtaining the theoretical masses from computer models that may not include the full modeling and/or physical properties of the internal wiring, connectors, etc.

With regard to fingertip forces, it was observed that in most cases where these are reported, no distinction is made between short term ("maximum") and continuous ("rated" or "nominal"), and static and dynamic performances. Similar observations were made for the measurement of noise and speed under free or loaded conditions. In practice it may be presumed that the reported performance represents the best achievable, however, this would be a case of reader interpretation rather than designer communication.

A full list of potential mutually agreed artificial hand characteristics, yardsticks and, the definition of a standardized report and test system are beyond the means of this paper. Nevertheless, condensed draft lists of 'descriptors' (Tables II and III), physical properties (Table IV), and performance indicators (Table V), the majority of which can be found strewn across the artificial hand related literature, and that we find relevant to a standardized system, are given here. It is understood that without further standardization, the manner in which certain hand features would be described by different authors would tend to differ significantly. These Tables are therefore intended to provide a possible basis for the discussion on the standardization of the reporting system.

B. *Static and Dynamic Performances*

A multi-fingered, dexterous hand is in principle intended for grasping and manipulation, and hence both the static and dynamic performances across the ranges of motion are of great relevance. The net force output depends on the finger joint positions, the load, the type of actuators and transmission systems implemented, and the speed of execution, in addition to other factors such as the orientation of the links, the internal resistance to motion, and the control system. Hence, given all possible circumstances, the sole use of fingertip force indicators (e.g. maximum force and nominal force), does not seem sufficient to describe the performance of such devices.

In addition to the inherent force variations due to the kinematics of a finger, the instantaneous force or torque output of, for example, nonconventional actuators such as pneumatic artificial muscles or the flexible fluidic actuators implemented in [9] and [12], depends on the state of contraction or expansion and hence also on the finger joint position. The same is applicable to certain types of transmission systems such as those with rigid link mechanisms. The situation becomes more intricate when the fingers impart forces at a constant or variable speed, to for example displace or accelerate an external object. In direct current motors for example, the output torque available will vary with speed. Similarly, in a transmission such as a harmonic drive, the efficiency and hence the output torque depend on the input speed.

Thus given dynamic conditions, the mechanical power output capabilities of the finger(s) seem to be, in addition to the forces, adequate indicators.

Moreover, the device efficiency (the ratio of the mechanical work done to the energy consumed to carry out the task), could be a useful indicator of the effectiveness and state-of-art of the solutions implemented, especially due to the amount of miniaturized components placed in series, the number of factors that can increase the continuous or sudden resistance to motion, and the inherent characteristics of individual components. Hence, we suggest that the average and peak, device efficiency indicators should be also part of a standardized test and report system for artificial hands.

TABLE II. GENERAL PROJECT AND DEVICE DESCRIPTORS

Descriptor	Comments
Project Name	a distinct name with which the hand project may be identified
Institution(s)	the name(s) of the institution(s) carrying out the development
Related Publications	a list of those directly related publications that may provide additional details and insight into the presented hand
Development Status	the status of the presented device – e.g. research prototype, finished prototype, hand ready for commercialization, etc.
Hand Version	an identifier that represents a unique design status, and that similar to the revision of a technical document or drawing, is updated together with a list of the history of effected changes when design modifications are done
Device Description	a general description of the device and its appearance, accompanied by drawings and/or pictures that include any forearm or remote actuator package
Application	the intended field(s) of application and final purpose(s) of the device
Overall Capabilities	description of the general capabilities (in terms of grasping, force output, sensing, and communication) of the hand, and demonstration through a set of comprehensive and standardized experiments, and where possible, task execution

TABLE III. PHYSICAL AND HARDWARE DESCRIPTORS

Descriptor	Comments
Kinematic Configuration	the kinematic configuration, ideally illustrated through a kinematic layout, and a concise description of all the DOFs
Actuation and Transmission	a description of the type, number, location, and the physical and performance characteristics of all the actuators (including passive elements) and transmission components
Mechanical Framework	a description of the mechanical framework including the link geometry, any mechanical stops, type of joints, materials utilized, any special manufacturing processes employed, etc.
Contact Interface	a description of the outer surfaces of the fingers and palm, including any contact pads and/or skin layer, together with their properties such as material, compliance, surface texture, etc.
Sensory System	a description of the type, characteristics, number, location, and purpose(s) of the deployed sensors in the device
Control System	a description the control system, including the required hardware and software, together with a distinction between the physically in-built (into the hand or hand-forearm volume) and the externally located circuitry
Energy Source(s), Storage and Conversion	The type(s) of energy used, together with a description of any required energy storage device (batteries, gas cylinders, etc.), and/or energy conversion apparatus (pumps, dc power supply, etc.). In view of the developments in humanoid robotics and prosthetic hands, the location, mass and size of the individual elements (external or in-built) are of interest.
Wiring, Pipes and Interfaces	a description together with the design and implementation considerations of both the internal and external electrical wiring and/or fluid pipe systems, communication systems, and interfaces

TABLE IV. PHYSICAL PROPERTIES

Property	Comments
Mass	the mass of the hand, and any associated forearm or module hosting actuators, sensors, electronic circuits, etc.
Centre of Mass	the centre of mass of the hand or hand-forearm combination
Size / Volume	The length and cross-section and/or volume of the hand, links, and any associated modules. A labeled diagram showing the link dimensions, together with the mounting configuration of the fingers to the palm, could provide a more complete description.
Modularity	a description/discussion of the level of component, finger and device modularity

TABLE V. PERFORMANCE AND OTHER INDICATORS

Indicator	Comments
Range of Motion	the achieved, maximum range of motion(s) of each joint expressed in degrees or radians
Working Volume	the practical, working volume of the hand (expressed in standard units), and the related, individual finger and thumb capabilities
Working Environment	discussion and demonstration through acceptable procedures of the suitability and where relevant safety, of the device in the intended working environment(s)
Speed	The average and maximum speeds for each joint (expressed in standard units) during free operation and with an external, standard load. The time it takes for the hand to completely close from the fully open position, or similar, as encountered in some publications, is also of interest as it may provide an additional but more comprehensive metric regarding the overall achievable performance.
Step Response	the response of the joints to a step input movement command expressed through the time constant and any other relevant indicators
Bandwidth	the bandwidth of the different joints during frequency response test experiments
Resolution, Accuracy and Repeatability	the resolution (expressed in standard units) of each joint, and the accuracy and repeatability of the device during free motion and while positioning an object in space (in both cases, when measured under standard test conditions)
Noise	the continuous noise (sound) generated during free operation and while handling a load under standardized test conditions
Smoothness of Operation / Grace	given the number and complexity of mechanisms together with the presence of wires and/or other connections, then the 'degree of smoothness' (or the lack of instantaneous mechanical jerks, 'stick-slip' effects, excessive vibration and noise, etc.), during free operation and while handling an external load, should be, at least subjectively, evaluated under standardized test conditions
Reliability and Endurance	Reliability has been indicated in [22] as one of the problems affecting the use of dexterous multi-fingered hands in major applications. Hence, the related considerations and testing done at both component and hand levels, should be highlighted. Some form of standardized endurance testing for the purpose of further investigation and correction that for example includes the recording of unfavorable events during a reasonable period of 'continuous' operation, and that takes into account the circumstances of robotic hands (typically expensive, in the research stage, and with one or very few samples available), should be envisaged.
Active and Passive Compliance	the description of the implemented control and hardware features that endow the hand with active and/or passive compliance capabilities, together with the demonstration of their extent and effectiveness
Controllability	the description and demonstration of the capabilities provided by the implemented control system, during free operation and while handling external loads
Energy Consumption	those energy saving features such as the possibility to maintain the grasp without power, and the energy consumed (ideally normalized with respect to the mass or size of the device), while performing a set of predefined and standardized tasks
Cost	while the research stage status of most of the projects is acknowledged, an indicative but realistic price range in which proposed devices could be positioned can be of interest for the purpose of comparative analysis and future development
Applied Forces	the nature (maximum, minimum, short term or continuous) and magnitude of fingertip and grasping forces that the hand is able to apply under standardized and clearly described conditions (static, dynamic, joint position, link orientation, grasping posture, object size, etc.)
Power Output	the average and peak mechanical power output of the device during a standardized task
Efficiency	the average and peak efficiency (mechanical wok done / energy consumed) of the device during a standardized task

C. Dynamic Test Procedures

Fig. 1 depicts a potential test setup, which is equivalent to that of a finger compressing in flexion with its tip a spring. In the setup shown, flexion of one or all of the finger joints will pull the tendon and cause the drum to act against the torsion spring. Throughout the movement, the instant angular position of the drum, and the time taken between successive positions, are measured and recorded.

The work done against the spring and the mechanical power may be calculated and plotted against the angle of rotation (for example), using the known spring stiffness and the recorded variables. After compensating for any frictional losses in the instrumentation and the inherent inertia, the peak and average mechanical power output capabilities of the finger during this task may be calculated. If the power drawn by the actuators is recorded, the efficiency (during the task) of the finger mechanism complete with the actuation and transmission system may be calculated as well.

For the 'whole' hand, identical indicators may be obtained through the setup shown in Fig. 2, where alternatively to the power grasp shown, a precision grasp may be used to squeeze the hydraulic liquid filled ball.

The experimental procedures just described could be in principle applied to any type of finger or hand, irrespective

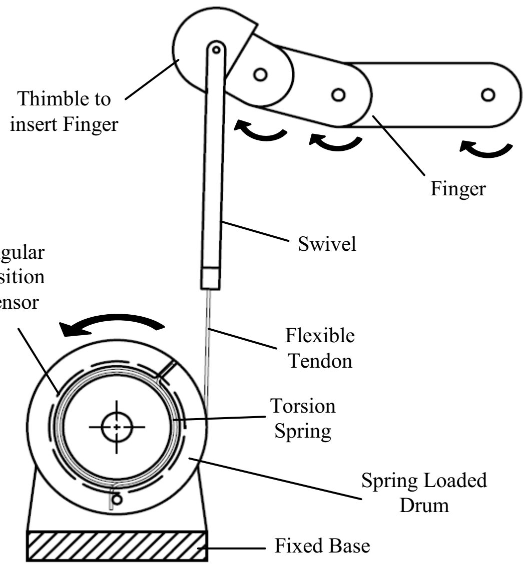

Figure 1. Finger Dynamic Test

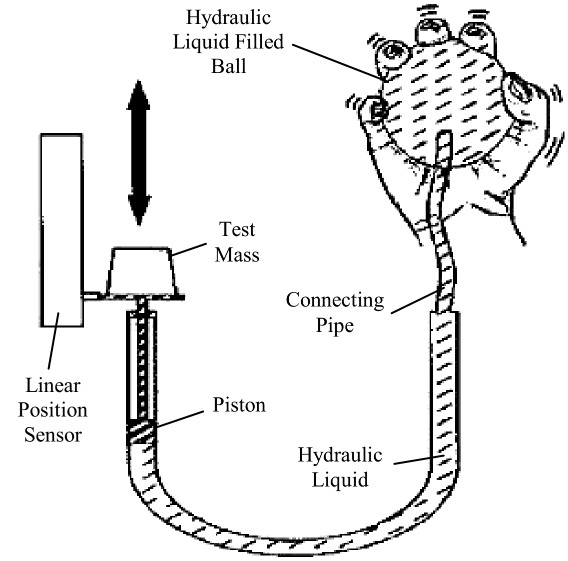

Figure 2. 'Dynamic' Spherical Grasp

of whether the finger DOF are individually controllable, rigidly coupled, or other. It is also possible to carry out the same tests using the human finger(s) or hand. In any case, directly comparable indicators ensue where the testing is carried out according to a standard procedure, using identical and calibrated instruments. Concerning the efficiency, this may be calculated, where it is possible to measure the power drawn by the actuators. In both examples given here, an instrumented finger thimble or ball could provide direct measurements of the applied forces. Further, a comparison of the power drawn and the relevant power installed (depending on the number of simultaneously activated actuators), might provide additional insight into the control system and strategy used during the tasks.

V. CONCLUSION

A standardized report and test system for artificial robotic hands should not be viewed as restricting the freedom of research. On the contrary, it is intended to assist the device improvement process so that the situation pointed out in [22], regarding the lack of implementation of such devices in real applications, can be transformed. Throughout this text, the term 'minimum' has been used purposely in conjunction with the 'set of indicators', 'grasping postures', etc., to allow the freedom for additional information, demonstration and experiments as desired.

New test procedures may not always be necessary to demonstrate the reported properties and performance of the hand. A variety of procedures and instruments to objectively measure several mechanical characteristics of the *human* hand already exist. Examples include dynamometers and grip analyzers for the measurement of grip strength; goniometers for the measurement and verification of the ranges of motion, and; esthesiometers and discriminators for the testing of sensation. Some of these test instruments and/or the respective procedures could be applied to artificial hands.

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Authors' Information

Carmel Ellul

RIAL, Department of Industrial and Manufacturing Engineering
University of Malta
Msida, MSD 2080
Malta

Tel: +356 2340 3091
Fax: +356 2134 3577

email: carmel.ellul@eng.um.edu.mt

Dr Ing. Michael A. Saliba
Corresponding Author, *Member, IEEE*

RIAL, Department of Industrial and Manufacturing Engineering
University of Malta
Msida, MSD 2080
Malta

Tel: +356 2340 2924
Fax: +356 2134 3577

email: michael.saliba@um.edu.mt