Innovative biorobotic system DDX for the analysis of neuro-motor conditions: methodology and results

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Abstract

This paper deals with a biorobotic system originated from studies of robotics. As consequence of the developments on a mechanical robotized hand, the research has carried to a special device for measurement of neuromotor disturbances.
The system, called DDX, is a device which in the medical field measures many kineto-dinamic parameters of the motion of a finger. The results allow to evaluate the health state of an individual.
DDX is characterized by a small dimension design, smart sensors, dedicated software. Because of easy portability, DDX can be used for medical applications, for daily health-care and for sport. The measured parameters are reaction time, speed, strength and tremor. The device is characterized by a voice detection system.
Test results are reported, to show some significant information obtained by DDX. The development of the project is occurring inside the DAPHNE, a European Union Project.

1. Introduction

The goal of the research is to measure quantitatively the neuropsychomotor conditions of an individual. This objective allows to detect individual state of health. The proposed system DDX measures a set of parameters connected with the human finger controlled motion. They are: reaction time, speed, force and tremor. By processing these parameters it is possible to monitor an individual's state of health. Tests have been made on persons healthy or affected by a particular pathology such as Parkinson's disease. The research has demonstrated results which may be applied not only for a diagnosis of neuro-motor pathologies (e.g. Parkinson disease), but also to check daily health or to monitor sports performances.
The use of the DDX device by an individual for health-monitoring purposes may allow the detection of the beginning of a particular pathology. It may also provide awareness of the life style repercussions on psycho-physical wellness.
From the scientific point of view, DDX system has been designed looking at biomechanical characteristics of human finger (Ref. 1,2,3,4).

2. The DDX system

DDX is a biorobotic device. It is used for a soft touch. The person looks at the screen and reads words of warning and of start. In the same time, a sound, like a beep, gives the start signal. The person must press softly the button with index finger, with right or left hand. The exerted force on the button is measured, together with time response and with the velocity of the finger motion..

Fig. 1 - DDX system: portable system, button, feeder, cables

Sensors inside DDX measure the force and the deformations. The tremor before and during the pressure on the button is measured by a switch which detects oscillations of the hand. The time response is detected by the clock of the processor inside DDX. A software program interfaces the processor with the sensors and the person action. The information and the data appear on the screen in the upper part of DDX (Fig.2).
DDX is light and portable. User-friendly software and simple mechanics ensure autonomous and easy-to-manage training and testing.

Fig. 2 - DDX display with buttons for the control and the view of results

The flow chart of the system data acquisition, measurement, result presentation is reported in Fig. 3. Tests with protocols have been performed in the research and in the development, with cooperation of Hospitals and Centers of Research (Neurological Institute Besta, Dr. Carella, and ICP, Parkinson Center, Dr. Antonini). Two kinds of tests characterized by well defined test performance protocols have been used.

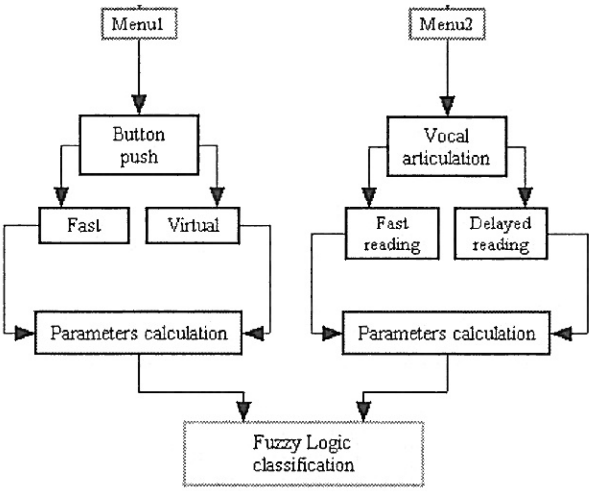

Fig. 3 Software diagram
The diagram shows the flow chart of the data acquisition, measurement, result presentation

The first type of test (*Button push*) is performed by placing the forefinger on the button and pushing it down softly. The motion must follow a visual-sound signal. In this way four kinetic-dynamic parameters, *reaction time, finger speed, finger force and hand tremor* (Ref. 10,11,12) are measured.

1) *Fast protocol* – The user starts with his finger on the button. After receiving a visual-sound stimulus, he / she pushes the button quickly and softly and releases it when the final position has been reached.

2) *Virtual protocol* – The user makes similar motion, in a virtual way. It means that he looks at the diagram on the screen which illustrates his / her finger movement with lines moving in the same time of the fingertip. The attention is focused on movement and "working memory" is activated.

In the voice articulation test, the person is asked to perform a reading test. The articulation capacities are examined for the possible diagnosis of speech anomalies. DDX may measure reaction time and offer a precursor signal of serious pathologies (Ref.9,21,22,23).

The two performance protocols are:

1) *Fast reading* – After a sound stimulus, the user is asked to read a word. The word appears on the screen in a random delay. When the word appears on the display, the person must pronounce the word quickly and correctly. DDX measures the *fore period,* i.e. the interval of time between the moment when the word is displayed and the moment when the user actually starts to utter the word. It measures also the *duration*, i.e. the time required to articulate the word.

2) *Delayed reading* – The individual is asked to wait before reading the word on the display. A sound notifies the user that he / she may start to read. By artificially delaying the time, the person is compelled to use his "*working memory*", performing a temporal transfer. Neurological studies confirm that the answer is generally given sooner than during *fast reading.* It is due to preparatory performance of perceptive processes and to connecting brain mechanisms, already excited during final neuro-motor processes.

3. Experimental tests

Experimental tests on healthy individuals confirmed neurology results. Test were performed on 25 persons, aged from 24 to 59 years, all healthy and not affected by particular pathologies. They used right and left hand, with both the fast and virtual protocols (Ref. 3,15,16). Results of the tests are shown in the below diagrams.

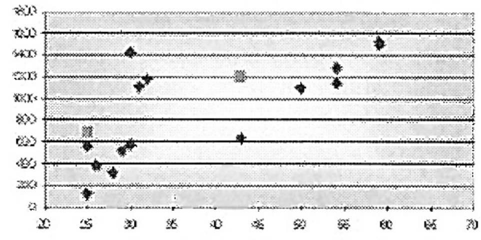

Fig. 4 – Reaction time graph
Horizontal: individual age; Vertical: time to react to the input signal; Triangles: individual average values; Squared: average in age sets

Reaction times present, as foreseen by neurology, an incremental trend according to the person age. However there are some exceptions to this rule, thus confirming the lack of absolute laws regarding behavior. DDX demonstrates that, as well known in neurology, each curve is linked to the individual characteristics of everyone.

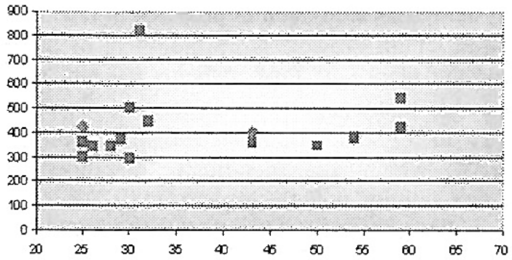

Fig. 4 – Speed time graph

Horizontal: individual age; Vertical: time to perform finger motion; Squared: individual average values; Triangles: average in age sets

The finger speed is measured by the time it occurs to reach the final position of the finger. Measurements was made in two age groups: 24-40 years, and 40-60 years. It is possible to note a lower time value, indicating a finger speed higher value, for younger group. This result confirms that individuals belonging to age group of 40÷60 have a greater capacity for concentration and better finger movement control, but a lower velocity of action.

The force is measured by a dynamometer inside the DDX system. The results show a very similar force for the group of patients, even with some personal differences.

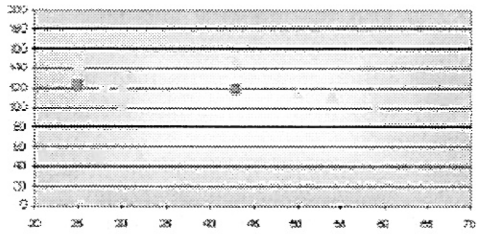

Fig. 5 – Force graph

Horizontal: individual age; Vertical: force of the finger; Triangles: individual average values; Squared: average in age sets

All results confirm that DDX is perfectly adherent to the results on neuromotor control, already known by neurology. The great efficiency of DDX is that the quantitative measurement of these parameters, except for response time delay, have never been measured all together quantitatively. This information has been confirmed in January 2001.

Tremor data highlight the probabilistic aspect of the analysis. Lower and less disperse values are noted in 40-60 age group. It is due to the fact that these individuals are likely to be calmer and more concentrated during test execution.

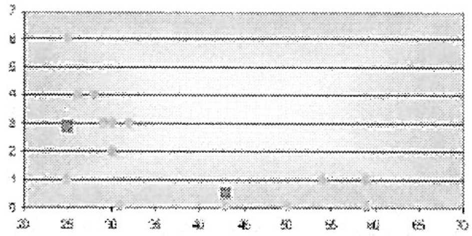

Fig. 6 – Tremor graph

Horizontal: individual age; Vertical: tremors of the hand in a fixed period; Triangles: individual average values; Squared: average in age sets

4. Results analysis and presentation with fuzzy logic

The data collected during the experimental tests on healthy persons have been compared with data of persons affected by Parkinson disease, already presented in Ref. 23. The results show that virtual reality tests with DDX detect the real brain behavior of the neuromotor control of unhealthy people. They are as quick as healthy persons in the reaction, but much slower in finger velocity. The force also is much lower for unhealthy people in comparison with healthy people.

To represent the quantitative results in a clear way, a classification model, based on fuzzy logic (Ref. 20) has been developed. Values measured by DDX are input parameters. They are: reaction time, finger velocity, force, tremor.

By means of fuzzy logic models, a fuzzification with neurological rules has been introduced. The diagram of Fig. 8 shows an example for the reaction time.

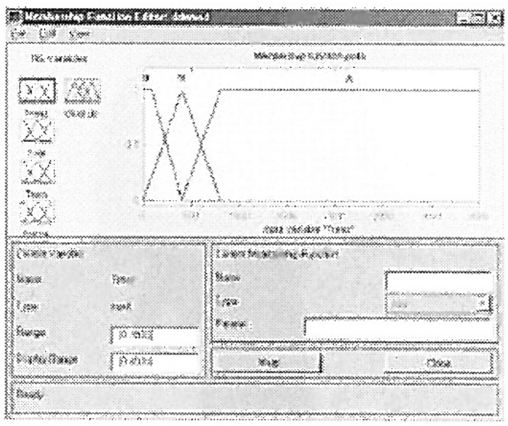

Fig. 7 - Fuzzy Logic

Fuzzy Logic application to Reaction time in a Matlab model for DDX, in order to have a simple representation of results

By means of fuzzy logic rules, an evaluation of the input parameters carries to fuzzy logic result. It represents the individual state of wellness with adjectives like : excellent, very good, good, sufficient, critical, etc, instead of digits which are sometimes difficult for interpretation and understanding.
The system is on development in a microprocessor of ST Microelectronics.

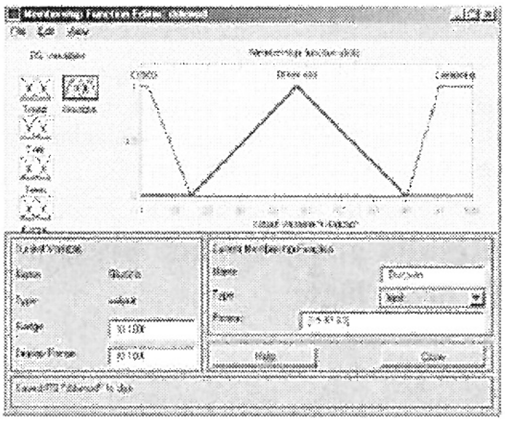

Fig. 8 - Fuzzy Logic (Output evaluation) in a Matlab model for DDX, in order to have a simple representation of results

5. New model with CAD design and rapid prototyping

Collaboration with neurologists and physiologists have resulted in the introduction of some modifications to the new model of the system, currently in the design phase. The system will still be compact and characterized by a user-friendly design. The display will be larger with a graphic matrix. Additionally, software and hardware will allow for storage, downloading and transmission of data to a remote site.

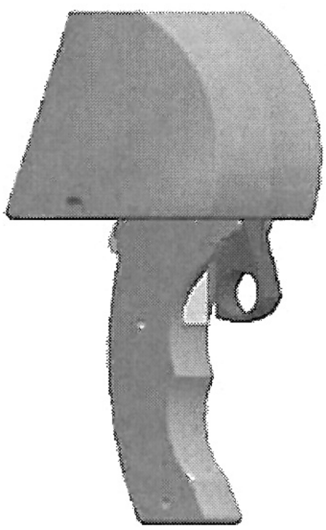

Fig. 9 – DDX new design and construction with rapid prototyping

6. Daphne project

The system is on study and in progress in DAPHNE, a European Union Project, as development of the main idea of the device of Prof. Alberto Rovetta, already presented in many papers (see References from 1 to 4, from 10 to 17 and 23). After the European project VREPAR, which was specifically theoretical, with short tests activity, now the project DAPHNE is carried on from Politecnico di Milano, ST Microelectronics, Agilent Technologies, University of Milan, Jump Design Studios. Pending patent on the system protects some special technological and scientific innovations.
The project needs the co-operation of neurologists to apply some biorobotic principles to neurology and viceversa, as a support for quantitative measures on neuromotor control, on disturbances in the motion, on stress analysis, on some mental sickness

7. Conclusions

The result here presented is a new equipment which can measure the status of neuromotor control. The control of motion in robotics has some algorithms derived from the cerebellum activity and from the motion in human action. In particular, the finger motion may be observed as the result of the activity of sensors, of actuators and of the control system. The methodology of research has applied the results of robotics and of bioengineering to the human touch. The touch expresses the action of the brain, of the neural activity and also the attention and intention of the human acts. The goal is the "touch soft" of a button. This simple action now is performed in billions of times every day, with cellular phones, keyboards of computers, etc.
The system measures the reaction time of the finger in front of the visual-audio signal of "touch", the velocity of the finger during the contact and the pressing, the force which the finger exerts on the button, and the tremor of the hand before and during the touch action. Furthermore, a sensor measures the time reaction by means of the voice of the person, when he / she repeats a word of difficult pronunciation.
All the data are connected with an acquisition system and the tests have been performed on healthy and unhealthy people, with real and virtual protocols.
Some results are:
1) the virtual reality application demonstrates that unhealthy persons, able to react actively with the attention and the intention in front of excitation, perform as well as healthy persons;
2) the finger force is lower for Parkinson disease affected people than for healthy people;
3) the data obtained by DDX well agree with the knowledge of neurological science
4) the action of drugs, alcohol and stress on patients is well evidenced by the system.

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The system is Patent pending No. 00201271.4

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