DESIGN AND DEVELOPMENT OF A SENSORIZED WIRELESS TOY FOR MEASURING INFANTS’ MANUAL ACTIONS


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Abstract—The development of grasping is an important milestone that infants encounter during the first months of life. Novel approaches for measuring infants’ manual actions are based on sensorized platform usable in natural settings, such as instrumented wireless toys that could be exploited for diagnosis and rehabilitation purposes. A new sensorized wireless toy has been designed and developed with embedded pressure sensors and audio–visual feedback. The fulfillment of clinical specifications has been proved through mechanical and electrical characterization. Infants showed a good grade of acceptance to such kind of tools, as confirmed by the results of preliminary tests that involved nine healthy infants: the dimensions fulfill infants’ anthropometrics, the device is robust and safe, the acquired signals are in the expected range and the wireless communication is stable. Results confirm the hypothesis that this typology of instrumented toys could be useful for quantitative monitoring and measuring infants’ motor development and ready to be evaluated for assessing motor skills through appropriate clinical trials.

Index Terms—Force measurement, infants, signal analysis, wireless communication.

I. INTRODUCTION:

COGNITION and action are mutually dependent. The starting point of development is not a set of reflexes triggered by external stimuli, but a set of action systems activated by the infant. Thus, from this perspective the development of grasping is an important milestone that infants encounter during the first months of life and this enables them to explore and learn about their environment. More specifically the grasping phase is highly dependent on the infant’s development. Efficient object manipulation depends on several factors: differentiation of individual fingers’ movement, grading of grip force, control over the release, bimanual action, in-hand manipulation. Maturation in each of these abilities assists the child’s mastery over objects and struggle toward competence. All these manual capabilities are damaged or delayed in infants and children with neurodevelopmental disorders; thus, from this perspective emerges the need to quantify this manual development and grasping capabilities in a rigorous way in order to objectively assess motor impoverishment in pathologic cases. This early diagnosis would open interesting perspectives on early intervention. In fact, currently, infants with neurodevelopmental disorders have rehabilitation sessions few times a week in rehabilitation centres but according to basic neuroscience it would be necessary to provide them with an early, intensive and multiaxial intervention. Engineering has brought supports in this field also in terms of devices and instruments for quantitative analysis of neuro-motor development, in an emerging field Neurodevelopmental Engineering. The main goals of this field were to propose instrumented tools for monitoring infants’ neuro-motor development and to provide a new quantitative approach for diagnosis and rehabilitation of neurodevelopmental disorders. In this work, we present the design and the development of a wireless sensorized toy for monitoring infants’ grasping development that can be used in an ecological environment. In addition the device has been designed in order to be able to measure in a quantitative way the grasping forces of each hand, during playing actions. By means of available low-cost technology and smart design, a new generation of devices would be useful for the assessment of infants’ motor development.

II. MATERIALS AND METHODS:

A. Clinical and Technological Specifications:

A continuous monitoring of the bimanual grasping actions in infants aged four to nine months-old, without being distressful to the infant, and to operate in an ecological environment are the objectives that clearly set constraints on the kind of technology used. The first two aspects considered when drawing down the requirements are that infants are noncollaborative subjects, i.e., it is not possible to ask them to perform given movement, and the need to measure their natural
movements, in an ecological setting. For these reasons, a toy has been chosen as the sensorized device for measuring manual actions in a transparent way, i.e., during the playtime without affecting the type of play or the type of grasping of the infant. In our case, affordance can, in part, guide the infant to perform certain movements instead of a bimanual approach through palmar grasp performed on the two lateral sides of the toy.

B. Design of the Sensing Device

Due to the ecological approach of this work it is not possible to know in advance the exact point of grasping on the toy, so it is preferred to employ types of sensors that can detect and measure a squeezing action in each point of the two lateral sides. At this purpose, a solution based on pressure sensors connected to air chambers, which allow estimating pressure changes inside these chambers, has been designed. This solution, with respect to a simpler one based on switch sensors, allows measuring the amplitude of the force applied independently from the grasping point.

The wireless sensorized toy was mainly composed of two soft sensitive parts made by elastomer shaped as a cylinder and a rigid case (made in epoxy resin) containing the electronic unit.

C. Materials:

Several commercial elastomers have been analyzed in terms of hardness, resistance, viscosity, manufacturing looking for materials with high compliance, easy manufacturing process, elasticity, and easy return to original form.
Electronic unit block diagrams: concepts of the End Device (a) and of the Coordinator (b).

**D. Electronic Unit:**

The electronics within the device are composed of three main elements: a communication board, a conditioning board, and the power unit. Outside, an external workstation, in which the data are stored and processed, is connected to the toy by using a wireless interface board. This interface board managed the data exchange from and to the device. Both the electronic boards within the toy and outside are nodes of a network.

**E. User Interface:**

A graphical user interface (GUI) has been developed in order to make simple and suitable to a wide range of users the electronic device. The software has been developed in C# language and it is connected to the coordinator by using the serial communication protocol (RS232).

**RESULTS:**

This section presents the results of the validation procedures meaningful divided in two categories: technical evaluation and experimental validation.

**A. Technical Evaluation:**

The technical procedures were aimed to investigate the mechanical behaviors of the silicone used in this work and the robustness of the assembled device. A quantitative study on the linearity of the stress-strain curve clearly shows that, despite the variability of the tested rates, the stress stress-strain curves can be approximated with straight lines. Concerning hysteresis, since it is an expected behavior for viscoelastic materials, the residual curve has been calculated for each stress-strain curve as the difference between stresses at the same strain, in loading and unloading phases. Results showed that the percentage indexes of hysteresis at different rates are lower than 2%, thus we can conclude that the hysteric effect is negligible.

Stress-strain curves on the silicone at different compression velocities.

Calibration curves for left and right sensors and relative linear interpolation.

By means of these results the designed
device can be considered robust and safe enough for the use in clinical trials.

The toy dimensions fitted with the infants’ anthropometrics and the light feedback embedded in the toy not only did not distract the infants’ attention but it stimulated an active play. Furthermore, thanks to the clear toy affordance, the infants performed the required grasping configuration: unimanual or bimanual actions on each side of the horseshoe. Thus, the toy design was useful in the discrimination procedure of the unimanual and bimanual grasping action, although it is still necessary amatching with the video analysis for verifying if the infant grasped the toy correctly and the relative hand used. The video recorded has been useful also to verify that thanks to the internal metallic core only the radial deformation, and so the squeezing actions, were detected by the sensors, as required.

The grasping actions are expressed in kPa in terms of maximum and mean values detected and standard deviation for the left and right sensor for each subject. Sensors activation thresholds were sensitive enough to detect the grasping actions and the acquired signals were in the expected range so that the sensors never came to saturation. The use of a pressure sensor with respect to some simpler solutions like switch sensors allow to quantitative measure the infant grasping actions and to detect strength impoverishment in case of pathologic cases such as infants with hemiplegia. The network traffic, observed by an external sniffer, showed the transmission time and the packets data that carefully respected the sampling time imposed and the data acquired. The packets lost are less than 1% and these losses were mainly caused by channel conflicts. The transmitting distance depended on the obstacles between Coordinator and End Device but it ranged from 20 m (severalwalls) to 100 m (open air) so for our application this distance is sufficient.

**V. CONCLUSION:**

The aim of this work was to develop a wireless sensorized toy for measuring infants’ manual actions. As pointed out, the clinical requirements set strictly technological challenges that need to be overcome. The use of silicone material has brought important contributions during the design phase as it allowed to shape the air chamber according to the infants’ needs (in particular the need of safe and attractive material) and infants’ anthropometrics. In addition, by varying the chamber thickness it is possible to tune the toy sensitivity and this feature is extremely important in applications with infants where the pressure exerted are very low and varying strongly with ages. Moreover, despite the use of viscoelastic materials, the hysteresis is negligible as experimentally proved. On the basis of these first experimental results a functional validation of the device has been obtained, in fact: 1) infants enjoyed the toys; 2) the toys met clinical requirements of measuring infants’ manual action; 3) the design of the toy has allowed to detect the palmar grasping actions of both hands simultaneously and separately; 4) the hardware and the software of the toy turned out to be robust, stable and safe (i.e., covers, data communication, and transmission, etc.).

The system has been provided with a GUI that it is extremely important for an interactive diagnostic tool. In fact the user can follow the trial in real-time and can set parameters and feedback. The infant behavior can be observed without the presence of an operator (e.g., the rehabilitation staff) in the same room. This is an important feature because the presence of the operators and the instrumentation could be distraction sources for the infant and consequently unmanned experimental variables that must be taken into account.

From electronic point of view, the approach used in this work and the scalar solution will allow a further miniaturization of the board. Moreover, the system can be extended so that several toys and consequently several infants’ behaviors can be observed at the same time. Several infants can play together with the same toy or different ones, and/or an infant can play with several toys. These are examples of interesting experiments that can be carried out by using the technique presented here. Next steps will exploit this tool in clinical trials that involve also infants with neurodevelopmental disorders with the aim to validate it as an auxiliary screening tool used by clinicians to have more data during the diagnosis evaluation. In a qualitative data scenario, as it often happens during the investigation of early diagnosis of neurodevelopmental disorders, this kind of device could be considered a supplementary tool that could give to clinicians quantitative information useful to make the clinical case more clear. In conclusion, the challenges and the efforts of this work are offset by the hope that this new family of tools could represent an important contribution in the development of auxiliary diagnostic devices used by clinicians in ecological environments that can be exploited for the screening of a wide number of infants with diagnostic and rehabilitation purposes.
REFERENCES:


