"BabyGlove": A Device to study Hand Motion Control Development in Infants

N.G.Tsagarakis[1]
School of Computer Science and Engineering, University of Salford, Manchester, UK. M5 4WT

Ben Kenward[2]
University of Uppsala, Department of Psychology, Uppsala – Sweden

Kerstin Rosander[3]
University of Uppsala, Department of Psychology, Uppsala – Sweden

D.G.Caldwell[4]
School of Computer Science and Engineering, University of Salford, Manchester, UK. M5 4WT

Claes von Hofsten[5]
University of Uppsala, Department of Psychology, Uppsala – Sweden

[1] e-mail: n.tsagarakis@salford.ac.uk
[2] e-mail: ben.kenward@wolfson.oxon.org
[3] e-mail: kerstin.rosander@psyk.uu.se
[4] e-mail: d.g.caldwell}@salford.ac.uk
[5] e-mail: claes.von_hofsten@psyk.uu.se

ABSTRACT

DataGlove input devices provide natural input control of interaction in virtual, multimodal and telepresence environments as they can monitor the dexterity and flexibility characteristics of the human hand motion. In this paper a new miniature hand input device named the "Baby Glove" is presented.

In contrast to the current Dataglove applications this miniature device was developed to study the sensorimotor control development in half to one year old infants and their ability to imitate. To meet the requirements of this application a device with a total mass of 5=40g including all the control hardware has been developed. An increased mobility wireless interface to the simulation computer is provided. This was realised with the employment of the Bluetooth radio technology.

Keywords: DataGlove, Bluetooth, Hand Motion Control Development, Infant.

1 INTRODUCTION

During the last decade the use of glove data input systems has been increased rapidly in many applications mainly in the area of VR and robotics [1-3], tele-surgery [4] and rehabilitation [5]. These devices are superior quality hand data input systems that can provide tracking for most of the hand motions while leaving the natural movements of the hand unrestricted. Tracking of hand motions in these input devices is achieved using a number of different sensor technologies including fibre optics, magnetic, or electrical resistance based sensors. In most of the cases the data gloves sense motions of the 5 or 4 fingers (the little finger sometimes is excluded).

The first glove-like data system is the Digital Data Entry Glove which was developed at AT & T Bell Laboratories in 1983. This glove was designed to measure hand positions including finger flexure, hand-orientation and wrist-position [6].

The VPL DataGlove is probably the best known of the data gloves developed with the research being funded by NASA. The DataGlove consists of a lycra glove with optical fibres mounted above the finger joints. VPL insisted that the finger bending accuracy of the DataGlove is 1deg, however, tests have shown that the accuracy of the optical sensor is closer to 5-10deg [7].

The PowerGlove was originally developed in 1989 by Abrams-Gentile Entertainment (AGE Inc.) for the Mattel Toy Company in association with VPL. Mattel released the PowerGlove as an accessory for the Nintendo video game system. These sensors of this glove are made of a double layer of conductive ink over supportive flexible plastic strip. Finger bending data is available for the thumb and first 3 fingers, with a resolution of 2 bits [8, 9].

The Exos Dextrous Hand Master is not really a glove but a mechanical hand exoskeleton system. The Exos Hand Master measures the position of all four joints of each finger using Hall effect sensors. A disadvantage that has been reported for this system is the weight of the unit (around 350g) [10].

Another glove, which has become popular in VR applications is the CyberGlove originally distributed by Virtex and more recently from Immersion. Its success is mainly due to the patented resistive bend-sensing technology that is linear and robust. The resolution of the finger position is 8 bits while the positional accuracy as it has revealed from test showed large deviation errors for repeated bending of the order of 5-10deg, and mean errors of 1-5deg [11].

The SuperGlove was manufactured by Nissho Electronics in Japan. This glove, which was released in May 1995, employs a new form of bend sensors, which was made by Nissho. The glove comes with 10 flex sensors (two for each finger and thumb) [12].

The 5th glove was released by Fifth Dimension Technologies (5DT) in order to fill the gap between very low cost and very high cost data glove systems. The optical sensors used for tracking of the finger bending provide 8 bits position resolution. The glove provides only finger flexion tracking and pitch /roll wrist tracking [13].

The Sensor Glove II was developed at the University of Tokyo. Each finger has 4 DOF, thus, the SG II has 20 DOF across the 5 fingers. A fixed base for all movements of the glove is constructed on a metallic plate fixed on the back of the human palm. The glove is combined with a complex cable-pulley transmission scheme which transfers force from remotely located electric motors. Rotary encoders located at the motor site measure the position of the finger joints [14].

In contrast with the data glove systems discussed so far, the Pinch Glove from FakeSpace does not measure the bending of the fingers but only detects contacts between the fingertips using simple conductive wires [15].

The TouchGlove is an alternative solution of the FakeSpace Pinch glove. In comparison to the PinchGlove the TouchGlove uses Force-sensitive resistors to detect contacts between the fingertips. It has 6 sensors in total, 5 at the fingertips and one in the palm, which measure the contact pressure with a resolution of 7 bits [16].

In this paper we present the development of a new miniature data glove input device for infants named the “BabyGlove”. In contrast to the previous systems mainly developed to provide natural hand interaction in VR environments this system was developed to provide an advanced infant finger motion monitoring tool to study the ability of infants to imitate and to investigate the predictive motor control of infants when trying to grasp an object of a particular shape. Apart of its tracking ability, “Baby Glove” provides increased mobility with its wireless interface that employs compelling Bluetooth radio technology.

This paper is organised as follows, Section 2 reports on the aim for the development of the “BabyGlove”. The next section introduces the system requirements. Following this, sections 4, 5 provide an overview of the system hardware and software illustrating the tracking facility and the system and application software. This is followed by preliminary assessment results of the system use. The paper will finally draw conclusions about the work with consideration of future work activities.

2 THE BABYGLOVE APPLICATION

The purpose of developing the “Babyglove” is to provide a system that is capable of monitoring the finger motions of infant users. This will be used in order to study:

i) infants abilities to imitate.
ii) how the infants use their fingers in object grasping.

This is very a different application from the current DataGlove applications where gloves are used to provide a natural input control for interaction mainly in VR applications.

For the first study two methods will be used. Images of moving hands will be shown to the infants with the “BabyGlove” measuring if the infants perform actions which resemble those they are seeing.

Secondly, a hand will be displayed to the infants, which is imitating them in real time. This will allow the investigation of their reaction to being imitated, using an eye tracker. An experiment will be carried out in which infants will first be allowed to learn that the on screen hand movements are contingent on their own. The finger correspondences will then be shuffled (so, e.g., the infant moves the index finger, and on screen the little finger moves). If this change surprises the infants (as measured by an increase in looking), then this will demonstrate that the infants have knowledge of the correspondence between their own fingers and the corresponding fingers of others.

The second study will use the “BabyGlove” to investigate how the fingers confirm to an object's shape before the moment of contact. It is known from previous studies by measuring just distance between thumb and index finger that the infant’s hand opens more to grasp larger objects [17]. “BabyGlove” will be used not only to confirm this predictive sensorimotor control but also to investigate other effects such as those of object shape or material.

3 BABYGLOVE DESIGN REQUIREMENTS

The development of BabyGlove hardware was based on a number of requirements as they derived from application needs and the user recommendations. Several key problems needed to be addressed in order to produce an infant finger monitoring system that is functional, while it meets essential requirements including unit size, weight, power consumption, simplicity in calibration and ease of donning/doffing.

The “BabyGlove” was designed with certain characteristics in mind. These include:

i) Tracking facility

This is the paramount system requirement to enable the finger motion monitoring. Considering the small size of the glove unit the selection of the sensor technology and the number of degrees of motion sensed are crucial.

ii) Simple calibration

The calibration of an adult data glove is usually a composite manual procedure involving the active contribution of the user. This procedure requires time and is difficult to be carried out on an infant user. The BabyGlove must provide a simple fast calibration procedure.

iii) Comfortable with ease donning/doffing

Based on the nature of the user the comfort of the infant hand needs to be preserved by proper selection of glove material. Fitting and removal must be simplified to prevent any discomfort during donning/doffing or even possible injuries to the infant fingers.

iv) High mobility:

The system must provide minimum restrictions on the infant hand motions.

v) Energy efficient

Since the glove will be used in infants to study sensory motor control developments prolong operation is very possible. The power consumption/system of the device must be carefully considered during the design process.

vi) Compactness

The system will be mounted on the infant’s hand and therefore the size of the system must be appropriate, figure 1, to provide good fitting. The size of a hand of an year old infant was used to define the “BabyGlove” dimensions.

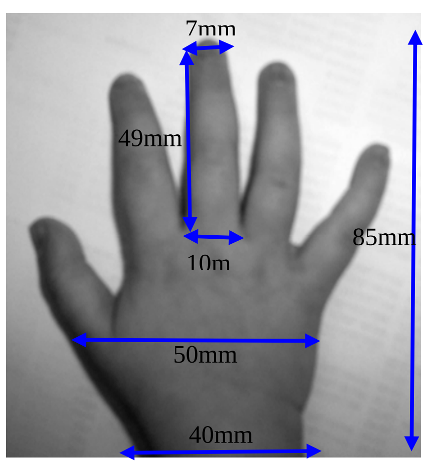
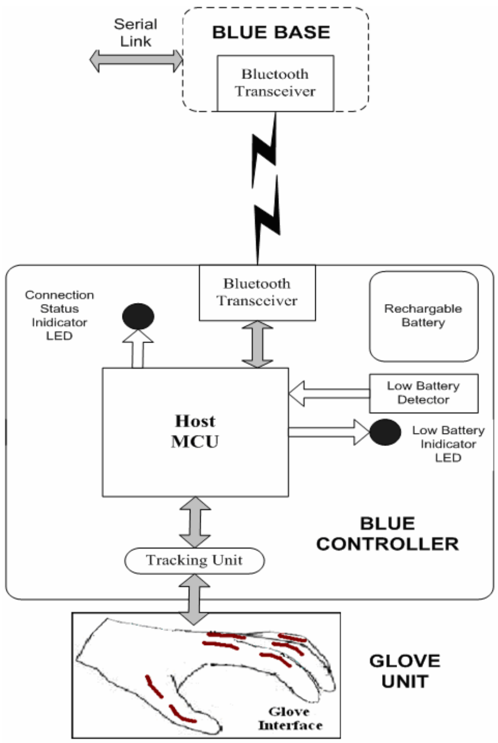


Figure 1: Basic Dimensions of a one year old infant hand used to specify the “BabyGlove” size.

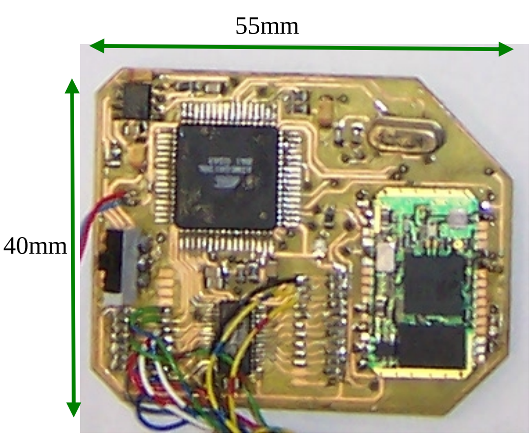
4 SYSTEM HARDWARE OVERVIEW

The “BabyGlove”, Figure 2, comprises three distinct physical modules: the “BlueController”, the “BlueBase” and the a wearable glove modules, figure 1.

The “BlueController” module is responsible for the control and interfacing of the glove module. It consists of the Host MCU, the Bluetooth transceiver and the tracking unit. The Host MCU is responsible for the acquisition of the signals coming from the glove sensors and the control of information exchange between the glove unit and the “BlueBase” module. The “BlueBase” module performs the information exchange between the “BlueController” and the Host Station.



(a)



(b)

Figure 2: System Hardware diagram and BlueController impelmentation.

The ssytem is powered by a mobile phone battery (3.7V, 750mAh) that is capable of supporting the system of 8 hours of continue operation. The glove module, Figure 3, which forms the housing for the variety of sensors/transducers, is constructed from lycra. Lycra was found to be the most suitable material combining strength, comfort and minimum restriction and interference to the infant’s finger motion.

Figure 3: The “BabyGlove “system.

4.1 The Wireless interface

Table 1 summarises the different features of the different wireless technologies considered during the design of the “Babyglove” system. The Bluetooth technology was employed to implement the wireless link between the glove and the host PC since it was found to be the most suitable method compared to other wireless alternatives like the 802.11 and the HiperLAN/2. These technologies were designed for wireless links with higher bandwidth and range requirements while Bluetooth data rate specification is closer to the data rate requirement of the glove interface [18, 19]. In addition since the “BabyGlove” is meant to be used in an area close to host station the Bluetooth was more suitable since it was explicitly designed for short-range cable replacement applications.

Table 1: Characteristics of the Wireless Technologies.

	IEEE 802.11	Hiper LAN/2	Bluetooth
Frequency	2.4 GHz	5 GHz	2.4 GHz
Range	100m	150m	10m (1mW)
Rate	11Mbps	54Mbps	721Kbps
Topology	128 Dev	128 Dev	8 Dev
Application	Wireless LAN	Broadband Wireless	Cable replacement

4.2 The Tracking Unit

The human index finger has three joints and four degrees of freedom. From the distal end, the joints are: the DIP (distal interphalangeal), PIP (proximal interphalangeal), and MCP metacarpophalangeal). The DIP and PIP joints have flexion/extension degree of freedom, while the MCP joint has both flexion/extension and abduction/adduction degrees of freedom. From this perspective the accurate monitoring of the hand motion would require motion sensing of all three joints. As this is difficult to be accomplished even in adult size gloves due to space limitations on the hand the number of sensing elements had to be reduced to a maximum number of 10. Although, this is a significant reduction it is believed that this will be adequate due to the nature of the experiments where only coarse finger posture identification is required. Since during normal finger motions the flexion/extension of the DIP and PIP joints are coupled on sensor on the PIP joint of each finger is used to monitor the DIP and PIP joints. A separate sensing element is used to record motions of the MCP flexion while MCP abduction/adduction movements are not monitored. Therefore, the BabyGlove unit is equipped with 10 resistive based bending sensors, which are located at the following joints on the hand.

Index Finger:	(MCP flexion, PIP flexion)
Middle Finger:	(MCP flexion, PIP flexion)
Ring Finger :	(MCP flexion, PIP flexion)
Little Finger:	(MCP flexion, PIP flexion)
Thumb:	(PIP flexion, DIP flexion)

The signals from the above bending sensors are multiplexed and sent to the Host MCU where they are sampled by a 10 bit A/D converter. This ensures sufficient finger joint position resolution (<0.2deg), which is above of any other existing glove based tracking system.

The selection of the bend resistive sensor was a compromise between robustness and accuracy. Although other more accurate sensing technologies were initially considered (strain gauges), their durability was not sufficient as large stressing of the glove is expected during the doffing process. Compared to strain gauges the bend resistive sensor offers increased durability but lower accuracy due to its nonlinear characteristics. To improve accuracy but also to simplify the calibration of the "BabyGlove" a study of the bend sensor response to bending was carried out.

To achieve this a single joint mechanical finger was inserted in each of the glove fingers. The mechanical finger joint was equipped with a miniature potentiometer for the purpose of the angle monitoring. The joint of the mechanical finger was appropriately placed beneath the bend sensor and a series of joint bending was performed while monitoring the sensor output signal and the angle of the joint.

To examine the effect of bending location along the main axis of the bend sensor the same experiment was performed by placed the joint bend axis of the mechanical finger in different locations along the sensor.

The profile of the joint angle against the sensor signals is introduced in Figure 4.

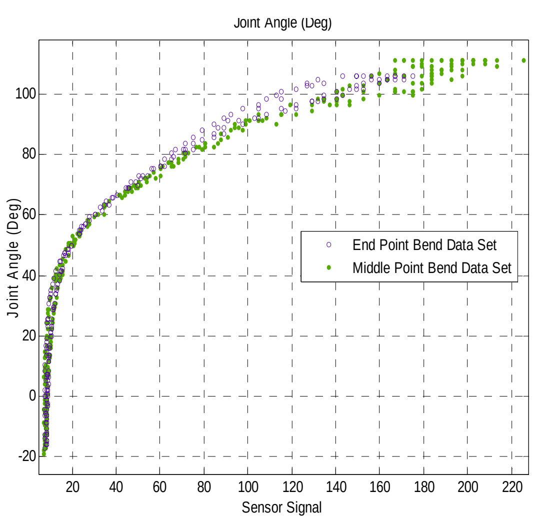


Figure 4: Joint angle and bend sensor signal profile.

The filled green spots shows the profile generated when the bend axis was in the central point along the bend sensor while the blue empty spots presents the profile generated with the bend axis close to the end border of the bend sensor. Figure 4 depicts a nonlinear response to bending with very low sensitivity for angles up to 45deg. Regarding the effect of bend axis location this appears to be not significant. Based on these observations and considering that the nonlinear profile of the sensor response can make calibration of the system challenging, compensation of the sensor nonlinearity is performed on the system software using a polynomial fit , Figure 5. This was estimated using robust least squares regression. For each individual element a unique fit of the form:

$$\vartheta = \frac{p_1 \cdot x^2 + p_2 \cdot x + p_3}{x + q_1} \tag{1}$$

was used. In the above equation x denotes the bend sensor signal and ϑ is the estimated finger joint angle. This compensation not only improves accuracy but also make easier the calibration of the system at the application software level.

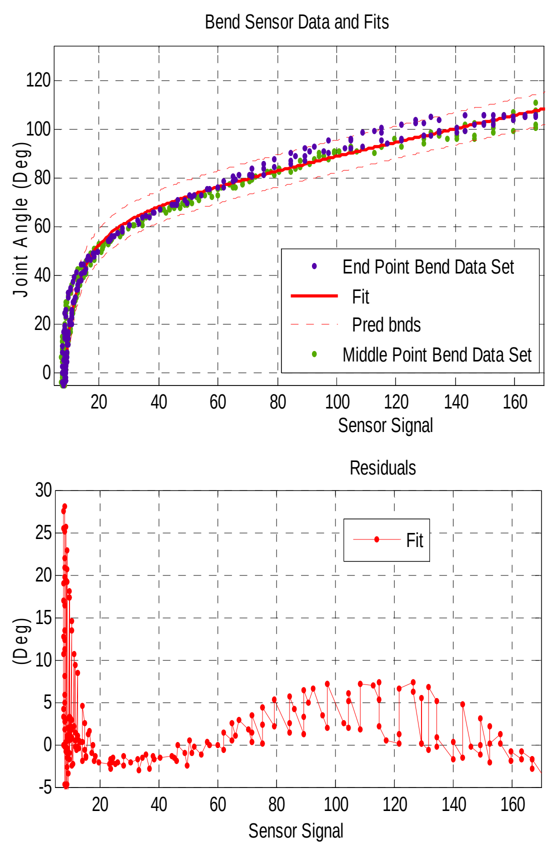


Figure 5: Joint angle and bend sensor signal fit.

5 SYSTEM AND APPLICATION SOFTWARE

5.1 Embedded Software

The "BlueGlove" embedded software, Figure 6, is split into two main modules; the input module and the Bluetooth stack.

The input part is responsible for performing all the data acquisition and sensor nonlinearity compensation tasks required for the tracking system. The Bluetooth stack module implements the software services required for the communication with the Bluetooth transceiver. The Host controller interface (HCI) performs device handling (initializing the device, packing and sending HCI command), HCI handling (unpacking HCI commands, HCI state machine). The main application interacts with the Bluetooth stack using setup functions, and by passing a callback structure to the HCI state machine. The stack calls specific application functions upon device initialization, connection establishment or sending and receiving ACL (Asynchronous Connection Link) data.

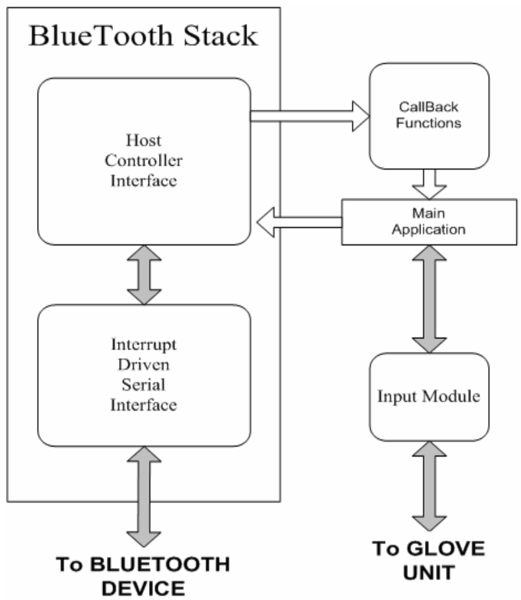


Figure 6: Organisation of the embedded software.

On system initialisation the main application depicted in figure 6, periodically makes a Bluetooth inquiry, in order to find "BlueBase" devices able to serve the glove interface. When connection is established input data can be transferred from/to the "BabyGlove" through the ACL connection, Figure 7.

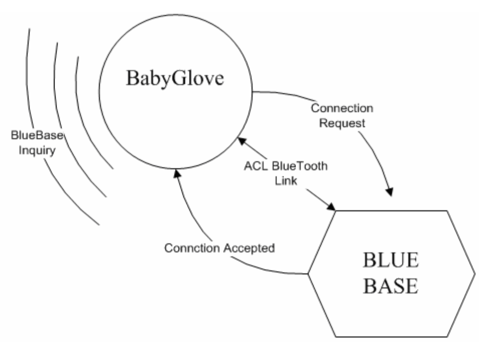


Figure 7: "BabyGlove" connection process with the "BlueBase".

5.2 Application Software

An application software named the "Babyglove" Toolkit was developed to allow the initial trials of the "BabyGlove" on infant users. A snap shot of the main application interface is depicted in figure 8.

Apart from its connection establishment service with the "BabyGlove" unit the "BabyGlove" toolkit provides two main facilities. These are the calibration and the data recording facility.

The Calibrate facility allows the calibration of each individual finger sensor. Each sensor value is associated with a particular gain and offset value. Using the gain and offset sliders the user can adjust the range of change of the sensor signal and map the signal range to the motion of the corresponding finger segment in the 3D hand avatar, Figure 9, which is simultaneously updated. As this procedure may be proved very challenging due to the nature of the infant user a semi-automatic calibration procedure is also provided. In this procedure the straight and feast hand angle vectors are used to automatically adjust the offset and gain coefficients.

Figure 8: The "BabyGlove" Toolkit application Interface.

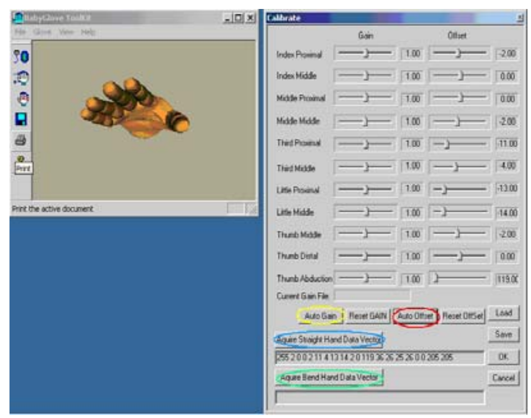


Figure 9: Snap shot of the "BabyGlove" calibration facility.

This procedure requires the infant to perform only a straight and a feast hand pose and therefore can substantially simplify the calibration of the system. Small corrections then can be performed using the gain and offset sliders. Gains and offset values can be saved to a calibration file that can be retrieved in the future.

The data recording facility was added to allow the storing of angle vector samples for further analysis. Data packets are recorded as the received by the device. A progress bar indicates the status of the recording. A time stamp is added to each of the packets using the system time. Recording can be stopped at any time if necessary.

6 BABYGLOVE ASSESSMENT RESULTS

The performance of the "BabyGlove" system has been assessed from a variety of perspectives including its ergonomics and feasibility as a finger motion monitoring system for infants. Table 2 summarizes the technical characteristics of the “BabyGlove” used in the initial trials.

Table 2: “BabyGlove” specifications.

Technical Characteristic	
Number of Sensors	10
Tracking Update rate	>70
Tracking Resolution	10bit (<0.2deg)
Communication Physical Interface	Wireless
Software Support	BabyGlove Toolkit

The glove systems has been tried in a number of infants (3) and initial assessments results related to the system calibration and ergonomic (fitting/removal) has been collected. Regarding its ergonomics the number one problem with the Babyglove was the difficulty of fitting. This was found to be very challenging since the infant users were trying to move their fingers during the fitting procedure. To make doffing easier the glove unit was opened on the inner side. This substantially reduced the fitting time.

Another issue reported during the glove trials is that when infants are wearing the “BabygGove” they don't want to move their hands. Putting it on a right handed infant turns the infant extremely left handed.

To reduce the glove effect on the infants behaviour in future trials dummy gloves will be distributed to parents in advance of sessions to try and get the infants more used to wearing it. As far as accuracy goes, errors in the range of 10-15deg have been reported. This is because of the calibration procedure that was difficult to be properly performed with the infant users but also because of the nonlinear response of the bend sensor.

However, this level of accuracy is considered adequate since accuracy is not that important in the imitation study. The grasping study will also concentrate on comparing hand position in different conditions, rather than reporting absolute finger positions. From this perspective the accuracy of “BabyGlove” is sufficient.

7 CONCLUSIONS

In this paper a miniature data glove interface named “BabyGlove” was presented. The “BabyGlove” was developed to provide a tool for monitoring the finger motions of an infant user with the ultimate goal to study the infants ability to imitate their predictive motor control capabilities during grasping.

An overview of the system hardware and software was presented in detail. Special attention was given during the development of the system in order to meet the requirements of size, calibaration simplicity and ease fitting/removal. To improve mobility BlueTooth radio technology was employed to provide the communication interface between the glove and the Host Station. Results form the initial system trials on infant users were discussed showing the feasibility of system as monitoring facility for the hand motions of infants.

Further research activities will involve improvement of the “BabyGlove” based on the assessment results form the initial trials.

ACKNOWLEDGMENT

This work is supported by the European Commission FP6, Project IST-004370

REFERENCES

[1] Yun, M., Cannon, D., Freivalds, A., and Thomas, G., (1997), An Instrumented Glove for Grasp Specification in Virtual Reality Based Point-and-Direct Telebotics, IEEE Trans. On Systems, Man & Cybernetics, 27(5): 835-846.

[2] Liu Y.H., Special Issue on Integrated Learning, Planning, and Control, Robotics and Autonomous Systems, vol. 32, no.5-6, 2000.

[3] Iba, S., Paredis C.J., and Khosla P.K, "Interactive Multi-Modal Robot Programming," International Conference on Robotics and Automation (ICRA) 2002, Washington, D.C., pp. 161-168, May 11 - 15, 2002.

[4] Y. Bar-Cohena1, Mavroidis C, Bouzit M. , Dolgin B, Harm D.L, Kopchok G.E, Virtual reality robotic telesurgery simulations using MEMICA haptic system, Proceedings of SPIE's 8th Annual International Symposium on Smart Structures and Materials, 5-8 March, 2001, Newport.

[5] Popescu V., Burdea G., Bouzit M. and Hentz M.D., A Virtual Reality-based Telerehabilitation system with Force Feedback , in IEEE Transactions on Information Technology in Biomedicine , vol. 4, No. 1, 2000.

[6] Grimes G, Digital Data Entry Glove interface device, Patent 4,414,537, AT & T Bell Labs, November 1983.

[7] Zimmerman T.G and Lanier J, Computer data entry and manipulation apparatus method, Patent Application 5,026,930, VPL Research Inc, 1992.

[8] Mattel Co., The PowerGlove, Company brochure.

[9] Gradecki J., The Virtual Reality, John Wiley & Sons, Inc 1994.

[10] Marcus B, Lwrence T. and Churchill P., Hand Position/Measurement Control system, US Patent 4,986,280, 13 pp., January 1991.

[11] Kessler G.D, Hodges L.F, Walker N., Evaluation of the CyberGlove as a Whole Hand Input Device, ACM Transactions on Computer-Human Interaction. 2(4), 1995, pp. 263-283.

[12]Nissho Electronics, The SuperGlove, Company brochure 1999.

[13]Fifth Dimension Technologies, The 5th Glove, Company brochure 1999.

[14]University of Tokyo, Sensor Glove II, http://dfs.iis.u-tokyo.ac.jp/Haptic/sgii.html.

[15]Fakespace Co., The Pinch Glove, Company brochure 1999.

[16] Infusion systems, The TouchGlove, Company brochure 1999.

[17] C. Von Hofsten and L. Ronnqvist (1988). "Preparation for Grasping an Object - a Developmental Study." Journal of Experimental Psychology-Human Perception and Performance 14(4): 610-621.

[18] Khun-Jush, J., Malmgren, G., ‘HIPERLAN type 2 for broadband wireless communication’, Ericsson Review, vol. 77, no. 2, pp. 108-119,2000.

[19] Arfwedson, H., Sneddon, R., 1999,‘Ericsson’s Bluetooth Modules’, Ericsson Review, vol.76, no. 4, 198-205