

# A wireless Bluetooth Dataglove based on a novel goniometric sensors

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**Abstract—** In this paper the design and construction of a novel wireless Dataglove based on new flexible goniometric sensor technology is described. The device is characterized by a low cost and rugged construction and no requires calibration before its use. Indeed, the sensors used are purely goniometric, so they are not sensible to dimensions of the user's hand. The Dataglove can measure the angular displacement of the fingers hand using 11 sensors, each sensor has a resolution of 0.2 degrees, with 3 degree of accuracy in the worst case. The communication between the Dataglove and its computer Host is carried out using a 2,4 Gigahertz Wireless Bluetooth radio protocol, in a guaranteed range up to 10 meters with a refresh rate of 100 Hz.

## I. INTRODUCTION

Dataglove is a glove fitted with sensors to measure the relative angular displacement of the finger limbs. Datagloves have been of high interest since the beginning of virtual reality, telerobotics and biomechanics. Datagloves may use several technologies: fiber optics, strain gauges, potentiometers, accelerometers or Hall effect sensors [1].

The fiber optics technology relies on polymeric light guides with a photo emitter and receiver at one end and a reflector at the other. The light beam is reflected at the end, the measured intensity returned to the base depends on the curvature of the beam. The optic fibers are mounted on a Dataglove and allow the detection of the fingers' movements. Zimmerman [2] presents a commercial example of this technology: the Dataglove, which is a neoprene fabric glove with two fiber optic loops on each finger. If a user has extra large or small hands, the loops will not correspond very well to the actual knuckle position and the user will not be able to produce very accurate gestures, in consequence the Dataglove requires recalibration for each user. Fifth Dimension Technologies (5DT, Irvine, CA) produces a Dataglove that measures two joints per finger using fiber optic sensors. Two versions (5-sensor and 14-sensor) of this expensive wireless sensor Dataglove are available [3].

Sama *et al* [4] presented other technology to construct Datagloves based on resistive strain gauges inserted in-between plastic slices. By curving the component, the resistance of the bend sensor changes and the angle can be estimated. These devices are placed on a glove for the acquisition. The devices based on this technology are precise and not encumbering, but their cost is high ( $10000 \div 15000$  USD) and they suffer reliability problems in the long time due to the high level of deformation. The Cyber Glove [5]

(Immersion Corporation, San Jose, CA) is the most significant example of this technology; it contains 5 to 22 strain gauges to measure individual joint movements. Another example is the P5 Dataglove (Essential Reality) [6], this cheap device –approximately 50 USD- uses one bend sensor per finger and transmits its position and rotation measurements to desktop mounted receiver using infrared emitters, its receiver range is limited to 3-4 foot.

Potentiometers have been used to construct Datagloves in applications where easy and fast implementations are required [7]. The main advantages of potentiometers are the low cost and the small size, its main drawbacks are firstly its tendency to capture electrical noise, secondly the contact between the wiper and the resistive element that reduces the life of the device and thirdly the thermal drift of the transducer.

Hand gestures are typically captured with alternative sensors, for instance, accelerometers integrate motion acceleration cues and filtering drifting errors for finger motions. Perng et al. [8] presented a system interface dedicated to hand movement recognition to enable mouse-like input using the Acceleration Sensing Glove, the Dataglove is equipped with six 2-axis accelerometers on the finger tips and back of the hand, it has also an RF transmitter to send data to a personal computer, thus acting a wireless glove device.

Hall effect sensors measure slow changes in magnetic field. The name Hall-effect refers to the physics process of bending the flow of electrons through a semiconductor, perpendicular to the magnetic field lines. This bending of the flow results in a displacement of electron concentrations and therefore a voltage difference. The Humanglove [9] is a sensorized elastic fabric Dataglove designed and commercialized by Humanware, it is equipped with 20 Hall effect sensors, each sensor measures data related to a DOF of the hand. The Exos Dexterous Hand Master is not really a Dataglove but a mechanical hand exoskeleton system. The Exos Hand Master measures the position for all four joints of each finger using Hall effect sensors [10].

People have different length, thickness of their fingers and size of their hands' palm, so it is necessary a calibration/normalization procedure to match the sensor output spans with the specific user range of motion. For all Datagloves previously mentioned, quantitative assessment of rigid range of motion (ROM) is required and a calibration measuring procedure must be done [11]. Calibration it is necessary when the Dataglove is made with sensors that measure

the deformations of the Dataglove itself, including those due to the variations of length occurring to a different user each time that wears the Dataglove.

In this paper we propose a Dataglove characterized by a low cost and rugged construction that does not require calibration before its use. PERCRO Dataglove (Fig.1) is based on absolute goniometric sensors [12] that measure the relative angular displacement between its transducing bulb and its tail (Fig.2), independently of the specific deformed elastic line of each sensor.



Fig. 1 PERCRO Dataglove

This paper describes the design, construction and characterization of a wireless Dataglove based on these novel goniometric sensors. The objective was to produce a Dataglove that would allow multiple angular finger joint positions to be recorded in static grip postures and in dynamic manipulative task using wireless technology.

The structure of this paper is described next. In the second section, we will give a brief description of the goniometric sensor. In the third section we will describe more deeply the characterization of the goniometric sensors. In the fourth and fifth sections, the hardware and software of this Dataglove is presented and then in the sixth section an evaluation of this device is presented. Finally, in the seventh section we will present the conclusions and the future of this work.

## II. THE GONIOMETRIC SENSOR

The sensor (Fig. 2) consists in a transducing bulb and a sensing flexing bar, with respective dimensions of (5 x 8 x 21) mm and (2.4 x 2.4 x L) mm where L is a variable length. Its support material is polyurethane and is therefore very rugged. The sensor comprehends very few components: a steel wire, a steel cable, a magnet, and one Hall effect sensor.

The working principle of the sensor relies on the fact that a flexible bar subject only to pure flexion has the property that the longitudinal elongation  $\Delta L$  of the fibers is proportional to the bending angle  $\Delta\theta$  and the distance of the fiber from the neutral axis  $w$ , see Figs. 2 and 3.

$$\Delta L = w \Delta\theta \quad (1)$$

A flexible but axially rigid cable inserted in a hole running parallel to the neutral axis of the bar, with one end fixed to the end of the hole, allows measure the elongation of the

fiber around the hole by acquiring the displacement of the cable free end. This quantity can be measured attaching a magnet to the cable free end and acquiring the intensity of its magnetic field by means of a low-cost Hall effect sensor.

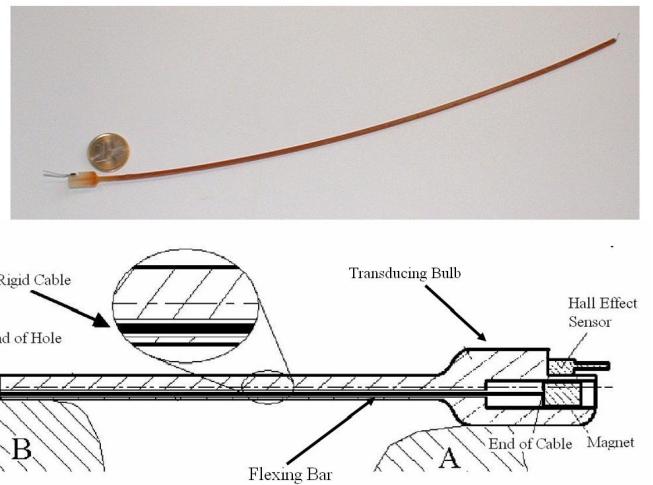


Fig. 2 The Goniometric Sensor

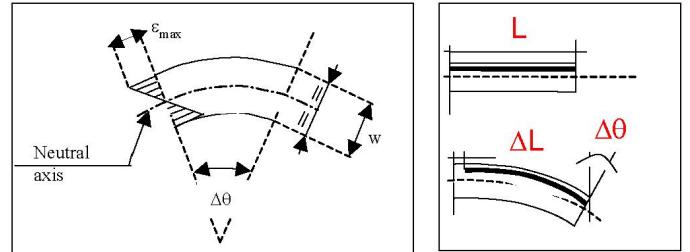


Fig. 3 The Working Principle of the Sensor

The resulting sensor is very rugged, it is not sensible to external magnetic fields, it has a low cost, and it provides a signal that does not require amplification. The following block-diagram presents a schema of the transformations involved in the goniometric sensor.

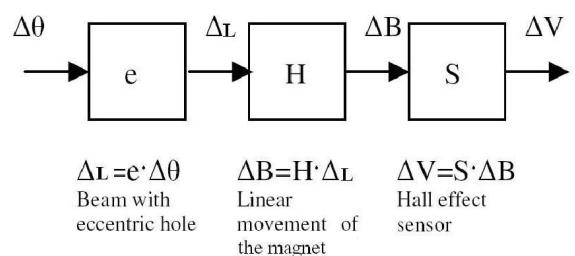


Fig. 4 Principle of measuring

Where

$e$  = eccentricity

$H$  = magnetic field variation per unit of linear displacement

$S$  = Hall effect sensor sensibility

$V$  = Goniometric sensor output

We have assumed that the overall relationship that rules the sensing system is described by the following linearized equation [13]:

$$\Delta V = S \cdot H \cdot e \cdot \Delta \theta = K_{\theta(\text{rad})} \cdot \Delta \theta \quad (2)$$

where

$$K_{\theta(\text{rad})} = S \cdot H \cdot e \quad (3)$$

inverting the relation (2) we obtain:

$$\Delta \theta = \frac{1}{S \cdot H \cdot e} \Delta V = K_{V(\text{rad})} \Delta V \quad (4)$$

where

$$K_{V(\text{rad})} = \frac{1}{K_{\theta(\text{rad})}} \quad (5)$$

$K_{V(\text{rad})}$  is the slope coefficient of the theoretical characteristic tension-angle of the sensor. Finally, the relationship tension-angle of the goniometric sensor is given by (6), where  $\theta_0$  is the angle measured when  $V = 2.5$  volts.

$$\theta = K_{V(\text{rad})} V + \theta_0 \quad (6)$$

To assure proper functioning it is necessary that the sensing bar is flexed only in one plane containing the cable and the neutral axis (as seen in Fig. 2), although small deflections outside this plane will cause only minor errors. Experimental results have shown also that errors due to shear forces are neglectable. The electric signals generated by the Hall Effect sensors ranges from 0 to 5V and are acquired by a microcontroller's ADC converter with 12 bit of resolution.

The resulting sensor performances are the following:

- Range of measure: (0-180) degrees
- Resolution: 0.05 degrees / Typically 0.2 degrees
- Accuracy: 3 degrees in the worst case
- Output span: 0-5V

Due to its flexible body, the sensor can be adapted to any external kinematics; in particular, it can be easily attached to the human body without exerting constraints. Resuming, the main advantages of the sensor are: the relation Angle-Voltage is linear, characterization is “for life”, the acquisition electronics is simple and its construction is very rugged.

### III. SENSOR CHARACTERIZATION

To convert correctly the analog output of the Hall effect sensor into an angular format, each goniometric sensor it had to be characterized previously. In order to make it, it is necessary to take samples of its output voltage at known bend angles to generate a regression curve and obtain the slope coefficient of the theoretical characteristic tension-angle of the sensor  $K_{V(\text{rad})}$  and the curve's offset. With these parameters, a given bend angle can be estimated from a given digital output.

In order to automate the characterization process, a custom hardware was built (Fig. 5); it is constituted principally of two bases; in a fixed base where the goniometric sensor is connected to external source of voltage and its output is

connected to an ADC of 16 bits of resolution of a commercial acquisition card (dSPACE 1103). A rotatory base is used to measure the bend angles using a quadrature encoder (2000 pulses per revolution) that is also to the acquisition card connected. Manually the rotatory base is moved while the output voltage and bend angle of the goniometric sensor are simultaneously sampled, then a Matlab script is used to obtain  $K_{V(\text{rad})}$  and  $\theta_0$  optimally interpolated from the experimental data.

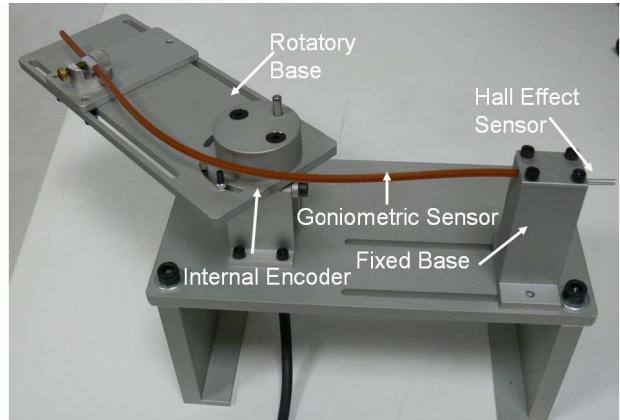


Fig. 5 Custom hardware to characterize the goniometric sensors

## IV. SYSTEM HARDWARE OVERVIEW

### A. The Dataglove

The Dataglove measures each finger with two sensors of different lengths for each finger; the sensors measure the angular displacement of proximal and medial phalanxes with respect to the back of the hand. The difference between the two signals is implemented in software in order to obtain the relative angular displacement between the two phalanxes. The flexo-extension of the distal phalanx with respect to the medial is considered equal to the medial with respect to the proximal; therefore just two sensors are enough to describe the flexo-extension of each finger.

The adduction-abduction movement of each finger is not measured, except for the thumb where a third sensor bends in a plane normal to the flexo-extension of the other two sensors. The sensors are mounted on the Dataglove with the bulbs fixed to the back of the hand, while the thin parts of the flexible beam are guided by sewn slots in order the bend adherent with the fingers. The sewn slots allow free axial movement of the sensor; this way, no axial force occurs and the sensor can measure an absolute angle (Fig. 1).

### B. Embedded Acquisition Electronics

An electronic acquisition unit has been built in order to acquire the analogical signals coming from the goniometric sensors, convert them to digital signals, and to send them to the computer using a Bluetooth protocol (Fig. 6).

We have used the microcontroller (uC) PIC18LF4423 operated with an external oscillator of 40 Mhz, 11 analog inputs have been used to read the output signals of the Dataglove's goniometric sensors using its internal ADC of

12 bits. Ten general digital input/output have been used in order to read/control external circuitry.

The communication between the uC and the class 2 Bluetooth device (F2M03AC2) is through its USART ports. The Bluetooth device enables a full duplex asynchronous transparent communication between the uC and the control computer; the communication between them is at 115,200 bits per second.

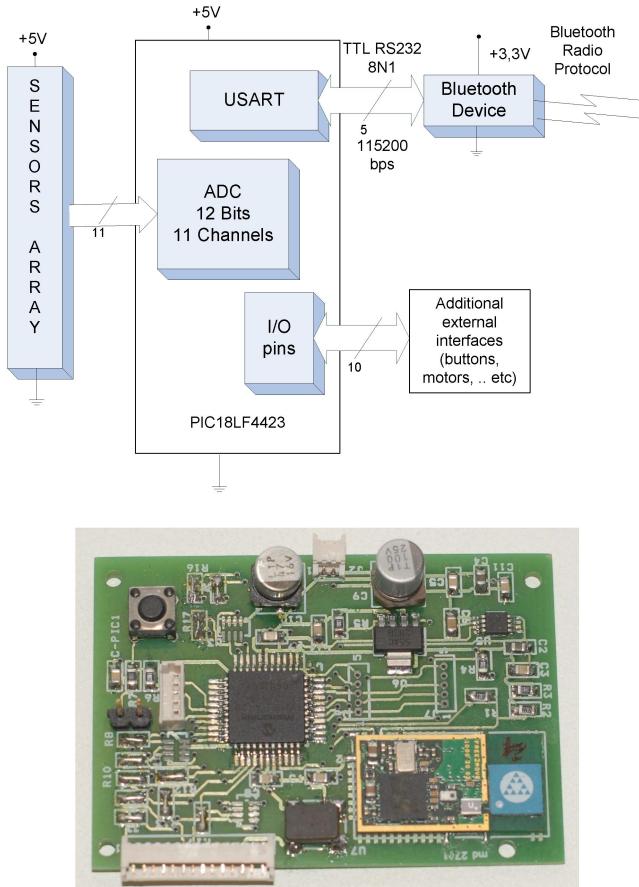


Fig.6 Dataglove ElectronicsArchitecture and its Implementation

The Bluetooth technology implements the wireless link between the Dataglove and the host PC, it is the most suitable method compared to other wireless alternatives like the 802.11 and the HiperLAN/2 [14]. Bluetooth is a radio standard and communications protocol primarily designed for low power consumption, with a short range (power class dependent: 1/10/100 meters) based around low-cost transceiver microchips in each device. Bluetooth differs from 802.11 in that the latter provides higher throughput and covers greater distances but requires more expensive hardware and higher power consumption. They use the same frequency range, but employ different multiplexing schemes. While Bluetooth is a cable replacement for a variety of applications, 802.11 is a cable replacement only for local area network access.

## V. SYSTEM AND APPLICATION SOFTWARE

### A. Embedded Software

The Dataglove embedded software is divided in two main modules, uC software module and Bluetooth Stack. The uC module is responsible of the data acquisition and packing of the Dataglove's signals, also it implements a quantization noise reduction algorithm that over samples and averages the sensor' readings, codifying each reading into a 16 bits of data.

The F2M03AC2's Bluetooth v1.1 stack module implements the software services required for the communication with the Host computer, enabling a virtual serial port connection between them (Fig. 7).

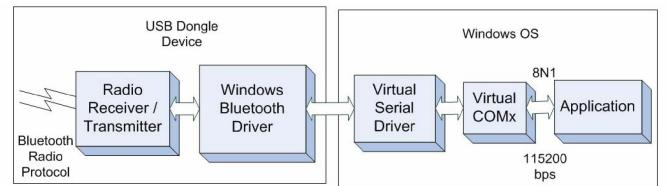


Fig. 7 Virtual Serial Port Connection with the Dataglove

When the uC receives a request command (2 bytes long), it responds with a frame of 26 bytes, the composition of this frame is described in Table I. Each component frame can be interpreted as an unsigned integer of two bytes of length; first the low byte is sent and then the high byte.

Table I. Composition of the Dataglove's Response Data Frame

Name	Usable bits	Data type
Packet Head	16 bits	Unsigned integer (2 bytes)
Thumb 1	16 bits	Unsigned integer (2 bytes)
Thumb 2	16 bits	Unsigned integer (2 bytes)
Thumb 3	16 bits	Unsigned integer (2 bytes)
Index 1	16 bits	Unsigned integer (2 bytes)
Index 2	16 bits	Unsigned integer (2 bytes)
Middle 1	16 bits	Unsigned integer (2 bytes)
Middle 2	16 bits	Unsigned integer (2 bytes)
Ring 1	16 bits	Unsigned integer (2 bytes)
Ring 2	16 bits	Unsigned integer (2 bytes)
Little 1	16 bits	Unsigned integer (2 bytes)
Little 2	16 bits	Unsigned integer (2 bytes)
CRC	16 bits	Unsigned integer (2 bytes)
Total		26 bytes

The packet's cyclic redundancy check (CRC) is calculated with the following relation:  $CRC = \sum_{i=0}^{11} sensor_i$ . Independently if the result of this summatory is greater than 0xFFFF (maximum value that can be saved in a two bytes variable), only the 2 two less significative bytes are saved in CRC.

When the Bluetooth communication link is working, a virtual full duplex 115,200 bps baud rate is guaranteed in the range of 10 meters. With this baud rate, a maximum of 492 frame packets per second could be transmitted. In normal operation the PC host application request to the Dataglove to send frames at rate of 100 per second.

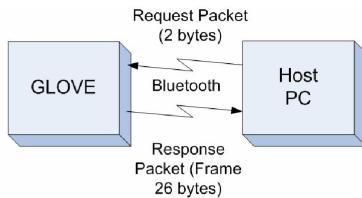


Fig 8. Communication Process between Dataglove and Host PC

### *B. Applications Software*

Two applications were developed in order to display graphically the measurements made by the Dataglove. The first application is a simulink S-function that displays numerically the value of the angles of the Dataglove (Fig. 9). The second, it is a graphical application that animates in real time an avatar of the user's hand. The graphic representation of the hand (Fig. 10) was developed by Graphics and Hypermedia Lab at the University of Cyprus, it has been implemented in a virtual 3D environment called XVR [15, 16], which is an advanced and lightweight system for the development of Virtual Reality applications both for the Web and for 3D Immersive systems. For this application, the angular positions of the skeletal joints are associated to the obtained angles, and then 3D hand meshes are deformed applying skeletal motions applying geometrical transformations to the point of the mesh associated to the corresponding point of the skeletal.

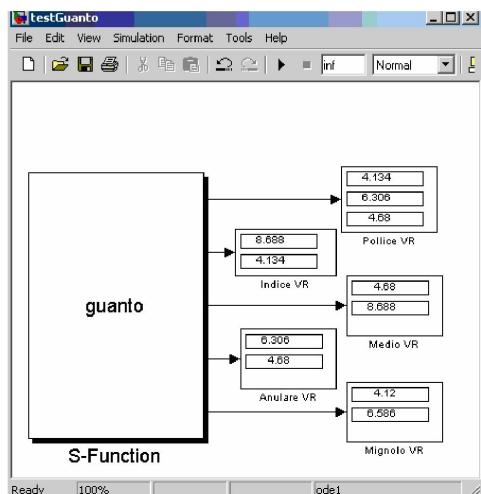


Fig. 9 A Sfunction developed in Simulink in order to estimate the sensor's angles of the Glove



Fig. 10 A graphical application where the Dataglove's measurements are displayed graphically in the Hand Avatar

## VI. SYSTEM EVALUATION

The performance of PERCRO's Dataglove has been assessed from a variety of perspectives including its ergonomics and feasibility as finger motion monitoring. Table II summarizes the technical characteristics of PERCRO's Dataglove used in the initial trials.

Table II. Dataglove Specifications

Parameter	Value
Number of sensor	11
Tracking update rate	Up to 492 Hz, 100 Hz guaranteed
Tracking Resolution	12 bits (0.05 degrees)
Accuracy	1 degree
Communication Physical Interface	Wireless Bluetooth 2.0 2,4 Gigahertz
Operation Range	10 meters

#### A. Power Consumption

The Dataglove power consumption at 100 Hz acquisition rate and 115200 bps of throughput is divided as follows:

Table III. Power consumption of single components

Table III: Power Consumption of single components	
COMPONENTS	Average Power Consumption (mW)
Power Stabilizers	0.4
Microcontroller	32
Goniometric Sensors	550
Bluetooth Transceiver	23
<b>Total</b>	<b>605.4</b>

Considering values in Table III, the four 1.5 volts AA rechargeable batteries of 2400 mAh provides to the Dataglove a continue operation of 24 hours. With the intention of expand the batteries time life, a watchdog and polling strategy have been programmed in the uC to reduce power consumption when reading are not needed, resulting an expanding factor of 30.

### B. Wireless Performance Analysis

To evaluate the system we tested the performance of the Dataglove in terms of packet loss. We measured how the distance between Dataglove and Host PC's Bluetooth dongle affect the correct reception of packets. The test consisted in counting packets correctly received based in the number of solicited packets.

Table IV. Percentage of packet loss

<b>Distance (meters)</b>	<b>Packet Loss (%)</b>
0.05	0
1	0
5	1
8	5
10	20
12	45
15	65

Table IV, shows that almost all the packets are received correctly in a distance range of 10 meters. In the range of 10-12 meters, the system decreases its performance but it is

still usable. For distances greater than 12 meter the system packet loss exceeds 40%. Thus our Dataglove usability is guaranteed within 10 meters, which is suitable for typical usage of this device.

## VII. CONCLUSIONS AND FUTURE WORK

The results are promising, PERCRO's Dataglove could have a wide commercial diffusion due to its low cost and robustness compared with its measuring qualities. Actually we are studying how to improve the overall performance of the Dataglove: 1) putting sensors for the adduction-abduction movements of the fingers, 2) putting a sensor to the back of the hand in order to acquire its movements, 3) developing a finite element model of the Dataglove in order to estimate the relative movements between the fingers and the sensors guides.

Future research will be aimed at reducing the overall dimensions of the sensor, also investigating similar goniometric sensors (i.e., substituting the steel cable with an incompressible fluid and the Hall effect sensor with a pressure sensor).

## VIII. ACKNOWLEDGMENTS

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