# SENSOR SYSTEM FOR AN ARTIFICIAL HAND

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***Abstract:*** *This paper presents a flexible digital design platform for the implementation of a Sensor System for an Artificial Hand using reconfigurable devices (FPGA) and a microcontroler. The purpose is to develop systems for artificial sensibility to be applied to hand prostheses and to patients with loss of sensory nerve function. The use of Artificial Neural Network (ANN) is essential to fulfill this purpose. This platform was developed in order to provide a fast prototyping environment. The microcontroler is used to implement the software part of a given application, and the reconfigurable device (XC4010XL FPGA- Xilinx) to implement the hardware part of the same application. The neural network is described using VHDL language, and Xilinx ISE4.2 software was used to implement it, in FPGA. By exploiting the easy reconfiguration capabilities of FPGA devices it is possible to implement many type of ANN. Using a Data Acquisition System and acquisition software the system provide an easy way to observe the results.*

***Key words:*** *Neural Network, Hardware Implementation, Field Programmable Gate Arrays, Sensor System, Artificial Hand.*

## 1. INTRODUCTION

The popularity of designing and building robot hands is demonstrated by the large number of universities and research organizations that have hands named after them. In the past, dexterous hands have been developed to perform laboratory research on grasping and finger manipulation. In parallel to this, the problem of developing prosthetic hands has been widely addressed in the field of rehabilitation technologies.

The human hand actually contains a total of 22-DOF contained in the thumb, four fingers, and the palm of the hand. This effectively results in a set of five 4-DOF fingers (robotic arms) mounted on a 2-DOF arm (the palm of the hand). Several robotic hands have been developed over the years, becoming increasingly anthropomorphic or human-like in their design as the mechanical issues relating to the packaging of a reliable dexterous device in a suitable package have been addressed and the problems mitigated. Many mechanical challenges still exist in terms of the stiffness and reliability of these hand designs, but development has reached the point where the hardware can support the development of appropriate control systems. The last two decades have seen increasing research attention being given to robotic hands and dextrous manipulation. Dextrous manipulation has been the key topic of interest in industrial assembly, prosthetic design, and also in the study of human movement. As a result of efforts triggered by these interests, dextrous hands were built in the United States, Europe, and Japan.

While significant milestones are being achieved in the design, construction and control of robotic hands, some key issues remain to be fully explored, including the challenging issue of sensing for a robot hand.

## 2. ARTIFICIAL HAND SENSING

Autonomous robot hands should possess dexterity, equilibrium, stability, and dynamic behavior. They must be controlled to achieve these demanding requirements. The optimal sensing mechanism, together with the control system, allows a robot to accomplish complex and difficult tasks by enabling it to react intelligently to changing conditions and the surroundings.

A dextrous robot hand needs as a minimum, a set of force and position sensors to enable control schemes like position control, force control and stiffness control [2]. Special types of sensors could be added to this basic sensor equipment (Table 1).

| Sensors | Sensor Type | Nr. of sensors | Range/resolution |
|---|---|---|---|
| Finger flexure | Fiber optic | 5 | 110º (8 bits) |
| Roll sensor | Tilt sensor | 1 | -60º la +60º/0,5º (8 bits) |
| Pitch sensor | Tilt sensor | 1 | -60º la +60º/0,5º (8 bits) |
| Force sensor | FSR | 6 | 0,5-10 N, rezol. 0,5% |

Table 1. Sensors of Artificial Hand.

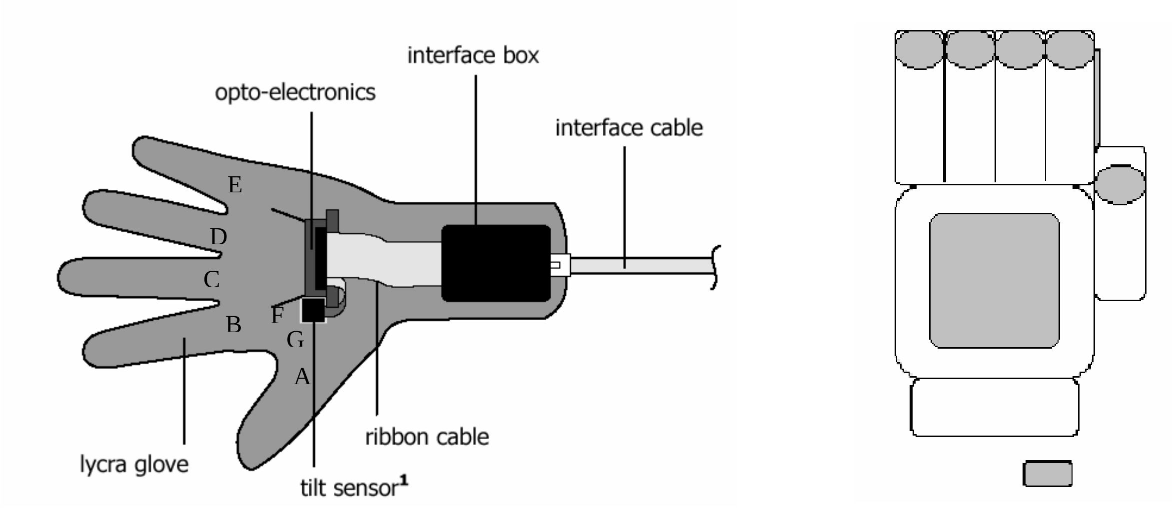
### 2.1. Position Sensing /Finger Flexure Sensors

Finger flexure angle sensors are located on all the fingers including the thumb. This system is designed for gesture recognition and use optical flexure sensor, one per finger, incorporated in a Data Glove [3]. The 5DT Data Glove measures finger flexure and the orientation (pitch and roll) of a user's hand. Figure 1.a shows the Data Glove that consists of a **lycra glove** with embedded fiber optic sensors. These sensors are linked to the computer via an **opto-electronics** unit, a **ribbon cable** and an **interface bo**x. The ribbon cable also joins the interface box to the **tilt sensor.** The 5DT Data Glove 5 connects to a 9-pin RS 232 serial port (DB9 connector) via the interface cable.

### 2.2. Force Sensors

In this design, 6 touch-pressure sensors are located on the fingertips as well as on the palm to detect contact with an object and the force being exerted. Figure 1.b shows the location of these touch sensors. The transducers used are the Force Sensing

Resistor (FSR) elements (made by Interlink Electronics) which are capable of sensing forces in the range of 20 grams to 5 kg.




a) b)

Fig. 1. The components of the 5DT Data Glove 5 and location of the sensors

### 3. HARDWARE AND SOFTWARE CONFIGURATION OF THE SENSOR SYSTEM

The system hardware design shows up a fully modular concept (Figure 2). This platform was adopted because it facilitates the use of codesign techniques [5].

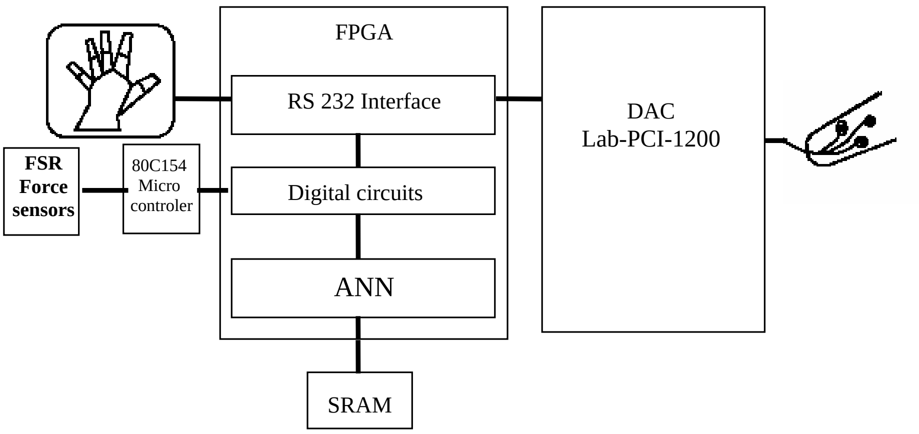



Fig. 2. Hardware configuration of the Sensor System

The platform was developed in order to provide a fast prototyping environment. It is based on a microcontroler (80C154) to implement the software part of a given application, and one reconfigurable device (XC4010E FPGAs - Xilinx) to implement the hardware part of the same application. Additionally, there is a local static RAM (32 Kbytes).

The XS40-010XL Board is perfect for experimenting with FPGA designs, microcontroller programming, or hardware/software codesign. The 20,000-gate XC4010XL

FPGA operates at 3.3V but is 5V-tolerant so it is possible to connect it to commonly available TTL chips. Digital logic designs can be loaded into the FPGA. The microcontroller can use the FPGA as a coprocessor. The SRAM can store microcontroller programs/data or serve as general-purpose storage for FPGA-based designs. The XC4000XL series of FPGAs is supported by Xilinx's Foundation and Alliance Series software.

The software part is described using the 8051 assembling language, and the hardware part is described using VHDL (Figure 3). The FPGA is configured using CAD tools for logical synthesis, technology mapping, placement, routing and download.

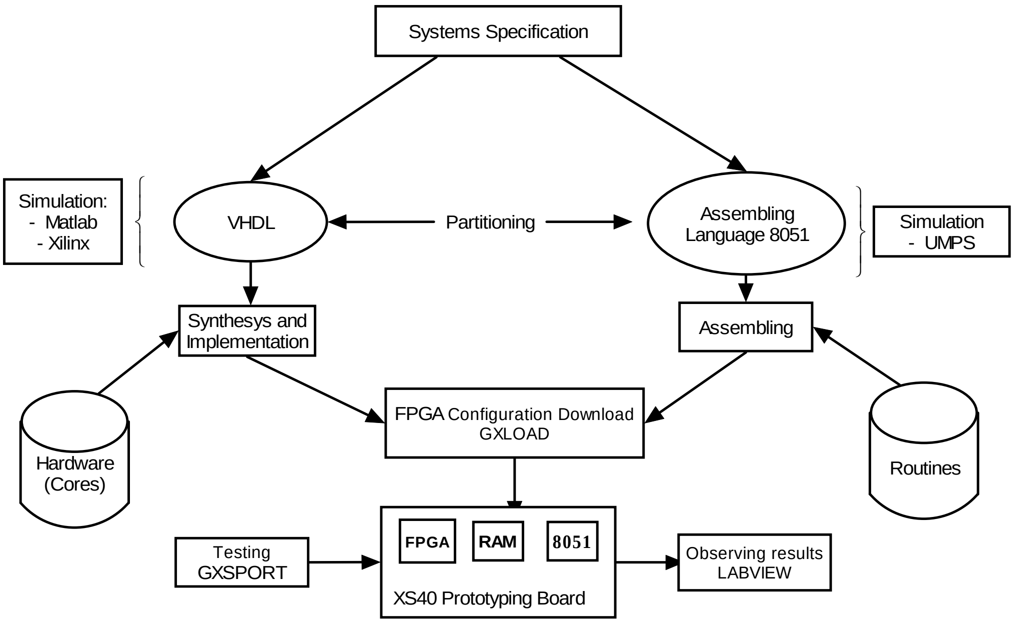



Fig. 3. Software Configuration of the Sensor System

## 4. NEURAL NETWORK IMPLEMENTATION

Modern reconfigurable (FPGA) devices can be used to implement neural networks in hardware [4]. Furthermore, digital implementation, using FPGAs, allows the redefinition of the topology using the same hardware.

### 4.1 Neuroprocessor Model

The model presented here for a neuron has one input, plus all the outputs, feeding into a summing junction whose output feeds a hard limiting activation function. The result is held in the output latch. Each neuroprocessor (NP) has only one input. If there are several inputs, then several NPs will be needed with one of them serving as a summing junction to sum several inputs. When translated to hardware, certain optimizations will be performed taking advantage of the simplicity of the model, reducing it to a minimum circuit.

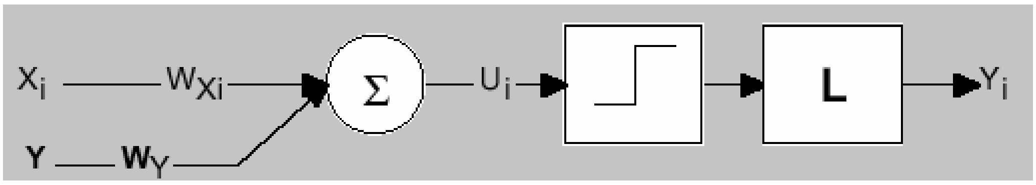



Fig. 4. Neuroprocesor Model

Inputs and outputs are binary in value. In hardware they are the logic values 0 and 1. For modeling, they are the sign bit of the sum. The logic value 1 represents a negative value and the logic value 0 represents a positive value. The weights are any positive or negative integer value. Summing all the inputs is simply done by adding up the weights, changing the sign of a weight if the input value is negative. The activation function takes the sign of the resultant summation and presents it to the latch. The latch passes the value on to the output on a positive clock edge.

Since the inputs are of two values, there is no multiplication and the entire NP can be run with addition. To make the addition even faster, the range of weights should be as minimal as possible. The inputs just determine the sign of the weight. If the input is nonzero, then the weight is complemented before adding.

The equations for an NP are:

$$U_i = X_i \times W_{X_i}^T + \sum_{j=1}^{N} Y_j \times W_{Y_{i,j}}^T \qquad (4.1)$$

$$Y_i(t+1) = signbit(U_i) \qquad (4.2)$$

A network of NPs or a NP net (NPN), can be shown by feeding in all the inputs and outputs into a summing junction. The X and Y inputs and $W_X$ weights for the X inputs are Nx1 matrices while $W_Y$ weights for the Y inputs is an NxN matrix, where N is the number of NPs.

The NP itself is described in about 40 lines of behavioral VHDL code.

ANN has been used to recognize complex signals from multiple sensors in order to associate specific signal patterns with specific movement of a virtual hand [1].

**5. TESTS AND RESULTS**

The developed experimental platform is presented in Fig. 5. In this project we explored two different ANN designs and implemented them in two different ways using the NP model. The two different implementations are just two of many possible architectures one can implement. For example we are implementing auto associative memory.

Research continues on the integration of neural network that allows the sensor system to "learn" hand gestures.

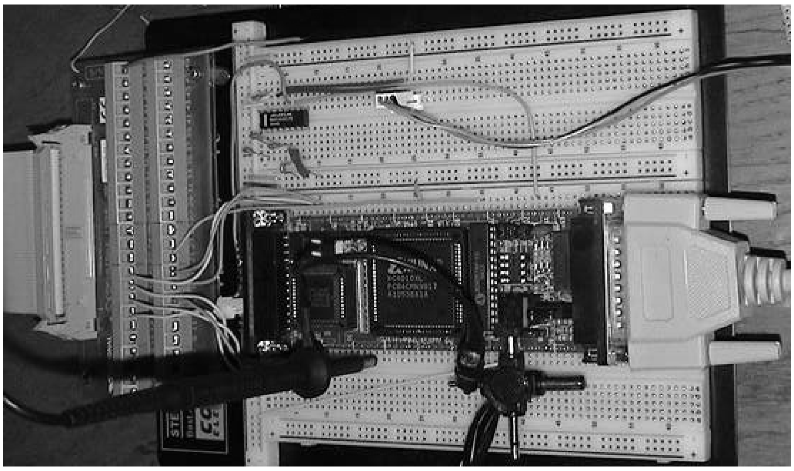


Fig. 5. Experimental Sensor System Hardware

## 6. CONCLUSIONS

In two experiments the principle of artificial sensibility has been tested by using force sensing resistors and flexure sensors. These experiments indicate that it is possible to create artificial sensibility in prosthesis or a hand with sensory dysfunction. The developed experimental platform offers grate flexibility for neural networks implementation by reconfigurable devices that could be used for hand gesture recognition.

The neural network description is modular, being possible to easily increase or decrease the number of neurons.

## 7. REFERENCES

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