FINGER FORCE SENSOR INSTRUMENTATION DESIGN

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DEDICATION

To the people that made a difference in my life; Javier, Catherine and Lisa Agraz that took me into their home without hesitation and give me a shot at the American dream. And to Dr. Ramon Betancourt, Dr. Greg Bailey, and Dr Robert Pozos, who without their guidance and support I would have quit school many years ago.

Who shoots at the mid-day sun, though he be so sure he shall never hit the mark, yet as sure as he is, he shall shoot higher than he who aims at a bush.

Sir Philip Sidney (1580, Arcadia).

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GLOSSARY

ADC	Analog-to-digital converter—an electronic device, often an integrated circuit that converts an analog voltage to a digital number.
AISENSE	Analog input sense signal
AMD	Advanced Micro Devices
ASIC	Application Specific integrated circuit. This device is the backbone of the PCI-MIO E data acquisition card.
CPHS	Committee On Protection Of Human Subjects
DAC	Digital-to-analog converter—an electronic device, often an integrated circuit that converts a digital number into a corresponding analog voltage or current.
DAQ	Data acquisition—a system that uses the computer to collect, receives, and generates electrical signals.
DAQ-STC	Data acquisition system timing control
GUI	Graphical User Interface
I/O	input/output
ISOMETRIC	Muscular contraction occurring when the ends of the muscle are fixed in placed so that significant increases in tension occur without appreciable increases in length.
ISOTONIC	Equal in tension
LED	Light Emitting Diode
MIO	Multifunction input/output
NI	National Instruments

NRSE	Single-Ended Non-referenced. All measurements are made with respect to a common measurement system reference, but the voltage at this reference can vary with respect to the measurement system ground.
OS	Operating System.
PC	Personal Computer
PCI	Peripheral Component Interconnect—a high-performance expansion bus architecture originally developed by Intel to replace ISA and EISA. It is achieving widespread acceptance as a standard for PCs and workstations; it offers a theoretical maximum transfer rate of 132 MB/s.
PGIA	Programmable Gain Instrumentation Amplifier
RAM	Random Access Memory
SSB-T	Flexy Force sensor
TTL	Transistor to transistor logic
VI	Virtual Instrument

CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

1.1 Statement of the Problem

Repetitive Stress Injury (RSI) is attributed to a number of overlying biomedical factors. Repetitive activities performed at work or leisure over an extended period of time, constant excessive load or effort and poor body mechanics are suggested as causes of RSI. In addition, medical conditions such as pregnancy, rheumatoid arthritis, and diabetes can also contribute to RSI. When RSI occurs at the wrist and/or fingers, persons complain of numbness, tingling and pain in the area of the thumb, index, and middle fingers. The pain often increases at night and can radiate to the forearm, upper arm and neck. Eventually the affected person loses strength in the affected hand and can no longer easily move the fingers.

The term given for this set of symptoms is carpal tunnel syndrome (CTS), which is the narrowing of the anatomical tunnel formed by the wrist (carpal) bones through which the median nerve travels (Figure 1.1). The compression of the median nerve influences its sensory and motor innervations to the thumb, index, and middle fingers causing tingling, numbness, burning sensation, weakness and clumsiness [1].

The U.S. Department of Labor (DoL) concluded that the CTS is the “Chief occupational hazard of the 90’s”, affecting around eight million Americans and accounting for 41% of all work-related injuries. It is estimated that 25% of all computer operators have CTS, and by the year 2000 the DoL estimates over 50% of

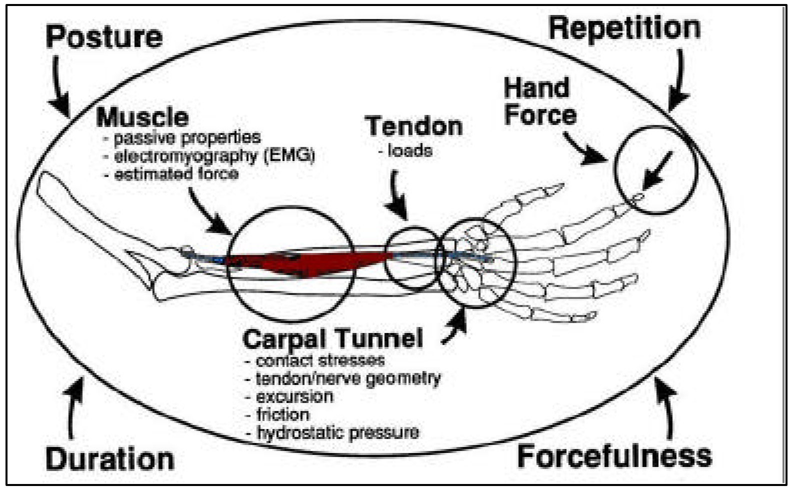


Figure 1.1 Biomechanical Risk Factors That Contribute To CTS

the workforce may be affected. Approximately 20,000 medical procedures are performed every year to correct various aspects of CTS; however, only 23% of all CTS patients are able to return to their previous professions after surgery.

Women are twice as likely to develop CTS as their male counterparts. Although they comprise 45% of the work force, they experience 66% of all work-related repetitive stress injuries [2].

The Occupational Safety and Health Administration (OSHA) estimates that by the year 2000, cumulative trauma syndromes will account for 50 cents of each dollar spent on medical care. The American Academy of Orthopedic Surgeons estimates that CTS cost 1 billion dollars annually in medial treatment. Each worker compensation claim for repetitive stress injuries can cost from $20-100K [3].

Keyboard usage exacerbates other repetitive actions that are associated with CTS. Carpal Tunnel Syndrome, and its associated pathologies, is common among persons who use keyboards or fretboards as well as flute and string players.

Treatment options for CTS vary widely, they include; surgery, Yoga, wrist splints that minimize wrist movements, specialized exercise equipment that strengthen the muscles of the forearm and fingers, and psychological support after the injury. The rationale for Yoga is that stretching and relaxing the wrist and forearm musculature can minimize CTS. Wrist--splints can often help, especially within three months of the onset of symptoms. Their use reduces the latency of the evoked electromyogram (EMG) of the median nerve. The latency measurement of the median EMG is considered the criterion standard for the diagnosis of CTS [4] [5]. Various exercise devices have also been reported to be effective. Flextend™ is an example of such a device designed to correct the imbalance between the flexor and extensor muscles of the wrist. Flexor muscles of the forearm are more powerful than the extensor muscles and may contribute to the onset and progression of CTS [6].

The diagnosis of carpal tunnel syndrome is difficult [7]. The classic procedure used to detect CTS via latency times of the median nerve and/or clinical evaluations have indicated that these two methods are not adequate to identify all patients who have the symptoms of CTS. Another method commonly used by the clinician is to evaluate the grip strength of the patient. This procedure requires the patient to maintain a constant amount of force for a minute or to rapidly grip and release a force-measuring device (dynamometer). This procedure does not mimic the real world, and its value as a diagnostic tool is questionable [7].

At present there is no objective measurement of the force that the fingers can produce when they are sequentially generating force on a keyboard while controlling the wrist angle. Although CTS is a major problem facing the work force and recreational groups in the United States, there is no reported method that quantifies pre- and post-finger force values after clinical intervention. In addition, there are no standards (e.g.: databases) of how much force one or all the fingers can generate while typing in a controlled situation. To develop such a database, a system is needed to collect and analyze finger-force data.

1.2 Background and Significance

At present the diagnosis of CTS remains controversial. Atcheson, Ward and Lowe evaluated 297 patients of whom 38% were diagnosed with CTS and studied whether there were any underlying pathologies that may contribute to the diagnosis of CTS. They concluded that a person with CTS is one who complains only of pain in his/her upper limb. [8].

The subjective criteria for diagnosis CTS consisted of the following:

1. At least one prior CTS diagnosis by a practitioner
2. The National Institutes of Occupational Safety and Health criteria for diagnosis of work-related CTS
3. Examiner's global assessment of CTS made by the examining physician, paired with clinical CTS criteria, and a distribution of the median nerve spreading of neuropathic symptoms.

OSHA has proposed that slowing of conduction velocity in the median nerve in the carpal tunnel may be related to such non-workplace variables as age, obesity, wrist dimensions and physical inactivity. However, physical inactivity can slow conduction velocity even more than repetitive forceful hand or finger use. Persons with CTS may also have problems associated with the tendons that connect the muscles to the fingers. Patients may complain of tendinitis, inflammation of a tendon the resulting in pain, tenderness and swelling and/or tenosynovitis, which is inflammation of a tendon sheath that covers and protects tendons at joints, causing pain, swelling, tenderness and functional disability.

1.3 Statement of Purpose

The purpose of this project is to describe a force-measuring device that records single- and multiple-fingers force profiles. This system will incorporate individual force sensors on an ergonomically designed and commercially available computer keyboard. In addition, software will be developed to record the subject's depression and release of single and multiple keys and the force profile of each finger-force level.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Anatomy of the Hand

The purpose of this thesis is to describe a force-measuring device that records single- and multiple-finger force profiles. The force profile that is produced is a function of the anatomical and physiological systems that control the digits. Thus a brief overview of the anatomy and physiology of the hand is necessary to better understand the finger force-profiles.

The bones of the hand consist of three segments: the wrist bones called the carpus, the bone in the palm called the metacarpus, and the individual bones of the fingers are called the phalanges (Figure 2.1).

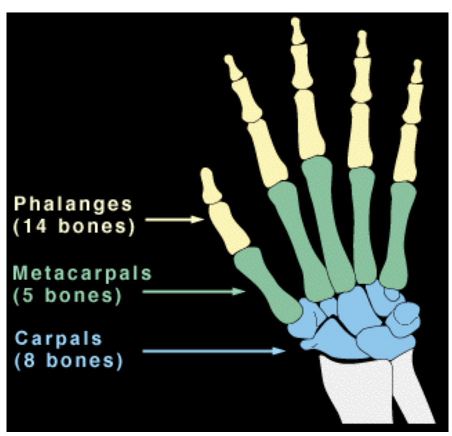


Figure 2.1 Hand Bones

The eight wrist (carpal) bones are arranged in two rows. The lower row starts from the thumb to the little finger (radial to lunar side), and the second row leads to the metacarpals. Although there are extensive articulations between the various wrist bones, the attachments of muscles to them do not significantly impact on finger performance.

The carpus overall is concave anteriorly and a ligament overlays this concavity forming the infamous carpal tunnel. This tunnel contains the median nerve and several long muscle tendons. Overuse and inflammation of the tendons compress the median nerve, which then influences the muscles that this nerve innervates, which influences finger movement and force development (Figure 2.2).

The five metacarpal bones of the palm have a number of important members. The metacarpal bone of the thumb is shorter and wider than the other metacarpals and is anatomically configured to accomplish the complex motor movements of the

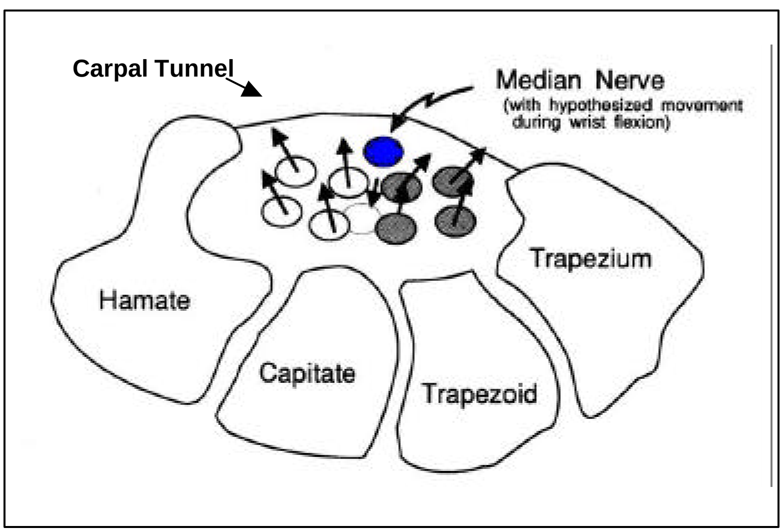


Figure 2.2 Cross-Section Of The Load Exerted On The Supporting Structures In The Carpal Tunnel And Its Hypothesized Movement During Wrist Flexion.

thumb. The base has a concavo-convex surface for articulation with the carpal bone, the trapezium, allowing for a wide range of movement. The thumb metacarpal has four different sets of muscles attached to it. The metacarpal bone of the index finger is the longest followed by middle, ring and little finger metacarpals. Each of these bones has multiple muscle attachments.

The phalanges are the bones of the fingers, of which there is a total of fourteen, three for each finger and two for the thumb. They are considered long bones and their distal ends are smaller than their proximal ends, which allows for each succeeding finger to articulate smoothly with the proceeding finger.

The first row of phalanges articulate with the metacarpals and the second row of phalanges; the second row of phalanges articulate with the first and third row of phalanges and the third and final row articulate with the second row (Figure 2.3).

2.2 Muscles that Move the Wrist and Fingers

The muscles that move the bones of the hand are either in the forearm, the extrinsic muscles, or are in the hand itself, the intrinsic muscles. The extrinsic groups of forearm muscles are both superficial and deep. The anterior superficial and deep muscles collectively flex the wrist and/or fingers. The posterior muscles of the forearm are divided into four categories; superficial, deep, intrinsic and extensor. The superficial and deep muscles, control extension of the wrist and fingers and also the fanning of the fingers. The intrinsic muscles are located in the hand per se and are best demonstrated by the lumbricals that cause the phalanges to fan when the hand is spread wide.

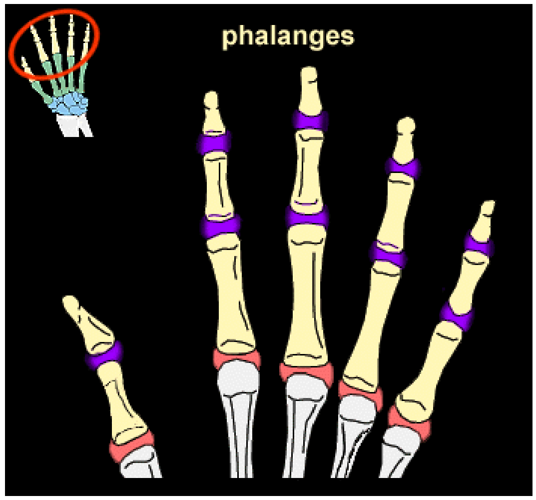


Figure 2.3 Finger Bones

2.3 Innervation of the Forearm and Wrist

Innervation of the muscles of the forearm and the hand are derived from the median, ulnar and radial nerves that originate from the cervical (neck) regions C5-C8 and thoracic (upper back) T1 vertebrae. The median nerve controls the flexor groups of the forearm as well as the intrinsic muscle of the lateral palm and first two fingers. The ulnar nerve controls the flexor muscles in the anterior forearm and most of the intrinsic muscles of hand. The radial nerve innervates primarily the extensor muscles of the forearm and wrist.

2.4 Muscle Contraction

There are two types of muscle contraction that the fingers perform: isometric and isotonic. Isometric contraction involves the contraction of the muscle without a change in the length of that muscle. Isometric contraction occurs when the person continuously depresses the key and not releases it. Isotonic contraction refers to a change in the length of the muscle while a constant force is being generated. Isotonic contraction is best exemplified when the fingers depresses and releases a key.

2.5 Physiology of Finger Movement

The large portion of the motor and sensory cortex that's devoted towards finger movement manifests the importance of control of finger movement**.** Studies of the mechanism(s) of coordinated sequential finger movements and force generation have been few. The scientific literature is rich with studies dealing with force generation of the limbs but hardly any exists that deals with fingers. The seemingly simplistic act of striking a key involves a number of steps that begins when the motor command is generated in the motor cortex, travels to specific areas of the spinal cord and then activates various wrist stabilizers and finger flexors and extensors.

Under normal circumstances, the finger force generated is sensed by various biomechanical sensors located in the muscles and joints of the fingers and wrist and is transmitted back to the spinal cord and higher centers. Hagbarth et. al. reported that the receptor for stretch in the finger muscles and the muscle spindle, play a role in controlling the stiffness of the forearm and finger muscles [10]. Birznieks et al reported that local friction on the surface of an object influences the amount of force produced by the fingers, suggesting that skin sensors also influence the amount of force generated [11].

2.6 Finger-Force Production

Finger force is generated when the muscles of the forearm and intrinsic muscle of the hand contract to depress a key. Parlitz, Peschel and Altenmuller, used resistive sensors to measure the dynamic finger force produced by musicians and non-musicians as they performed three different exercises of increasing difficulty [12]. They used a commercially available force-scan matrix fold (sensor array layers) (Tekscan), which contained 960 sensors per foil. The sensors were placed beneath five adjacent white keys on a grand piano. Their data suggested that mean force per touch and the mean touch duration for each exercise was greater in the non-trained subjects than in those trained [12]. Martin et. al. studied the relationship between the surface electromyogram of the forearm muscles and the keyboard reaction forces in ten persons who executed a keyboard task performed at a comfortable speed. Reaction forces were measured using a pair of load cells (conditioned force sensor) placed under the computer keyboard. Subjects were asked to type paragraphs that had all the letters of the alphabet. Peak forces ranged from 1.84 to 3.3N with an overall average of 2.59N, which is 5.4 times the Key Depression Force (the minimum force necessary to close the key switch). The force profile was greatest for the thumb, followed by the middle finger, then the index, ring and little fingers. Women generated twice as much force as men. Since the interkey delay ranged from 109 to 256 milliseconds (ms) and the keystroke duration was only 100-120ms, the authors concluded that the strokes were not influenced by feedback loops from the muscles or joints [13].

Gerard et. al. studied the effect of key stiffness on the development of fatigue, keyboard reaction forces and muscle electromyography. A strain gauge mounted under the keyboard amplified the force generated at the keys. They reported that subjects who typed for two hours generated four times the minimum force needed to depress a key and that the ratio of typing force to the electromyogram of the flexor muscles was not a good indicator of fatigue [14].

In a report presented on the World Wide Web, Dennerlein, Mote and Rempel studied the question of whether or not the index finger motion, forces and electromyogram were ballistic. Although they studied only one subject they presented data correlating the finger position, force and electromyogram. Force was measured with a load cell placed underneath the J key on a standard computer keyboard. Based on the bursting pattern of the EMG, associated with the activation of the forearm extensor muscle, followed by the activation of the forearm flexor muscle and subsequently the extensor muscle, they concluded that the finger depression on the key is ballistic [15]. Meinck et al reported a three-burst pattern of the extensor and flexor electromyogram during finger flexion. They also concluded that finger flexion on the keyboard was a ballistic movement [16].

In addition to the force profiles produced during finger flexion, there is an associated high-frequency tremor of 8-12 Hz found in the electromyogram. This frequency is associated with the synchronization of the motor units firing at that rate [17]..

CHAPTER 3

METHODOLOGY

3.1 Data Capture And Analysis Of Individual And Sequential Finger-Force Measurements

Prerequisites for the design of the sequential force measuring system were that it had to be designed to be used in typical situations, be easy to operate, and be inexpensive. Design considerations were based on the idea that it was to be a "plug and use" system, since non-engineering personnel would be using it. The system should be usable in various environments, so it must to be relatively insensitive to ambient temperature changes. A regular computer keyboard was rejected as the user interface since keyboard use varies from individual to individual and it would be difficult to standardize the wrist, hand or finger placement. Therefore, a specialized keyboard that minimized biomechanical differences was outfitted with robust sensors (Figure 3.1).

Figure 3.1. Inforgrip Inc. BAT keyboard.

Software considerations included the need for visual feedback to the subject, to insure that persons generated the same amount of force every time that they struck the key, and isotonic force data had to be recorded and stored. Based on other exercise studies, 80% of the isometric force value was taken as the target force value that each subject had to generate for each depression. Hence some form of visual feedback system of the force generated by the subject was required for the exercising of the subject. Another software consideration was that each force profile was to be visualized simultaneously in real-time from the time of onset of key depression and release. All force data would be saved and a fitted curve to the data would be plotted. Finally, an electronic record of each subject would be gathered previous to the data collection process, and would be stored with the force data.

This study measured finger force by using five resistive-based technology force sensors placed on the surface of individual keys to measure finger force for all

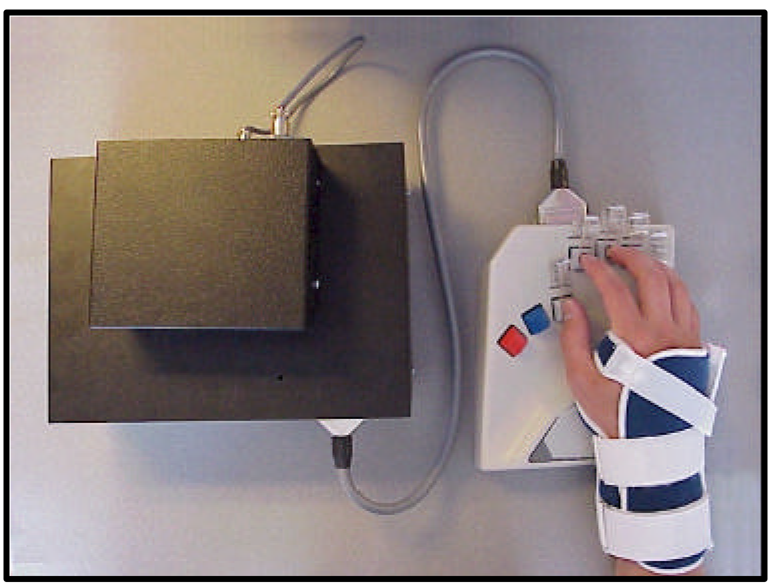


Figure 3.2. Entire Finger Force Instrumentation System Setup; Human Subject Hand, Force Sensing BAT Keyboard And Signal

five fingers, individually or in a group, on an ergonomically designed keyboard (Figure 3.2). A 16-bit data acquisition (DAQ) PCI (Peripheral Component Interconnect) card model number MIO-16-4 from National Instruments was used to capture the data from the five resistive-based force sensors. LabVIEW Software was written to record pertinent subject data, visual feedback of the force level each subject was required to maintain, and a best-fit plot of all data points, as well a curve to best fit the data.

3.2 Hardware and Software Design

The need for a "real time" data collection program with a graphical user interface (GUI) front end, demanded an industry-standard data acquisition system. The software that displayed the force profiles was developed using LabVIEW from National Instruments for Windows. The software ran on a generic personal computer (PC), AMD 300MHz, 64Mbytes of RAM with a Windows 98 operating system (OS).

3.3 Description of Hardware

3.3.1 System Block Diagram and Operation of Hardware

Three sets of hardware are used: force sensing keyboard, DAQ card, and signal-conditioning unit. (Figure 3.3)

3.3.2 The Force-Sensing Keyboard

The ergonomically designed seven key keyboard from Biomechanical Advanced Technology (BAT), is part of a design from Infogrip Inc. from Ventura city, California. This keyboard is used to increase typing speed. By using simple sets of key combinations that would represent letters, words, sentences, and even paragraphs. The BAT was chosen for its unique ergonomic design that reduces hand strain and fatigue by controlling the wrist angle. Only the keyboard shell and the key switches were used, the actual typing of words was not needed in this application (Figure 3.1)

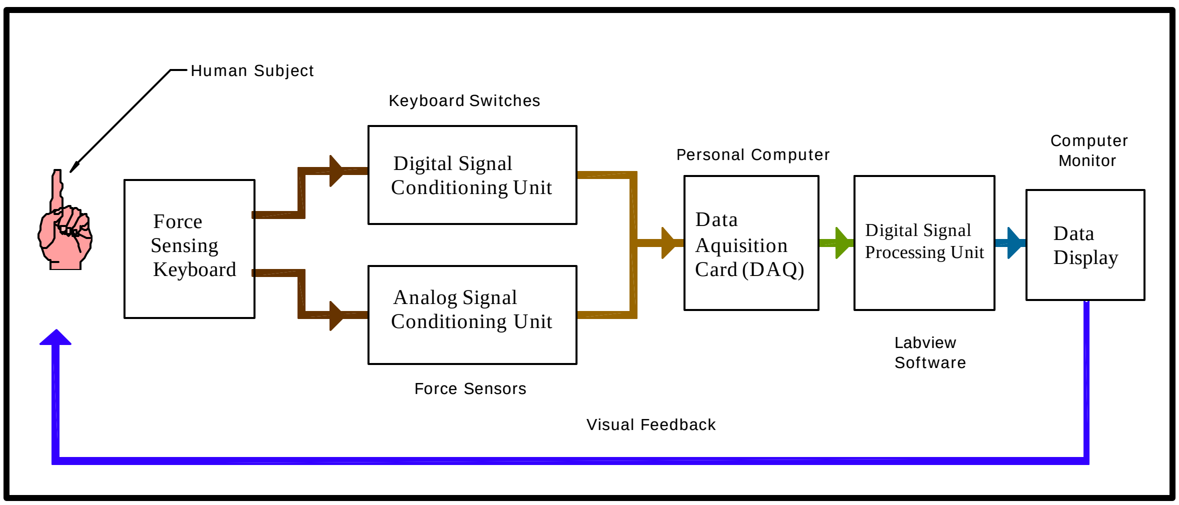


Figure 3.3. System Block Diagram of the Finger Force Sensor Instrumentation Design.

3.3.3 Sensor Evaluation

Prior to choosing the resistive-type sensors from Tekscan (SSB-T), other sensors that could be placed in the BAT keyboard were evaluated.

The following transducers were considered:

Piezoelectric Film and Coaxial Cable. Theoretically, a piezoelectric film sensor and a piezoelectric coaxial cable could be used, however the coaxial cable sensor size was too long and the film sensor was too small for use on the BAT keyboard. Thus the difficulty in positioning these sensors and their absorption of thermal energy (8v/°K) in the 7-20µm range made these types of sensors too cumbersome and too sensitive to environmental temperature changes to be workable. Under ideal conditions, the film sensor is capable of detecting human body heat radiation up to a distance of 50m (Piezo film sensors technical manual, Aug 98, Measurement Specialties, Inc., Valley Forge).

Strain Gauge. Strain sensors would work as well as the piezoelectric coax cable in theory. However, they are also very susceptible to environmental temperature changes as the piezoelectric material above, and posed major difficulties, and were thus rejected.

Semiconductor Pressure Sensor. Pressure sensors were also considered, but the required retrofitting of a keyboard, using hoses and fluid to measure multiple pressures, was considered too cumbersome and not practical.

Load Cells. Load cells were also considered. However, their high cost ($500/Cell), large size and weight offset their accuracy, leading to their rejection.

Resistive-based Technology (SSB-T) Force Sensor. After an extensive literature review, only one study was found for a device used to measure sequential finger force generated from the keyboard. This method used SSB-T sensors (Tekscan in Boston, Massachusetts) placed underneath piano keys. Resistive type sensors are ideal for this force-voltage type of instrumentation. Because of its linearity, flexibility, size, cost and minimum conditioning-hardware needed, the SSB-T sensor was considered the most appropriate for this application.

SSB-T Sensor Output Characteristics:

- Repeatability: within 5%
- Linearity: up to 80%
- Hysteresis: 50% loaded is less than 4.5% of full scale
- Drift: constant load less than 3%/log time
- Temperature: 0.2% per °C.

The SSB-T sensor is an ultra-thin (0-0.03"), flexible printed circuit. It is 0.5" wide and 6.3" in long (Figure 3.4). The force sensing area is a 0.25" diameter circle at the end of the sensor. The sensor’s area is constructed of two layers of polyester film substrate coated with a layer of silver, followed by a layer of pressure-sensitive ink. An adhesive laminates the two layers of substrate together to form the sensing area. The active sensing area is delineate by the silver circle on top of the pressure-sensitive ink. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. SSB-T sensors are terminated with a 3-

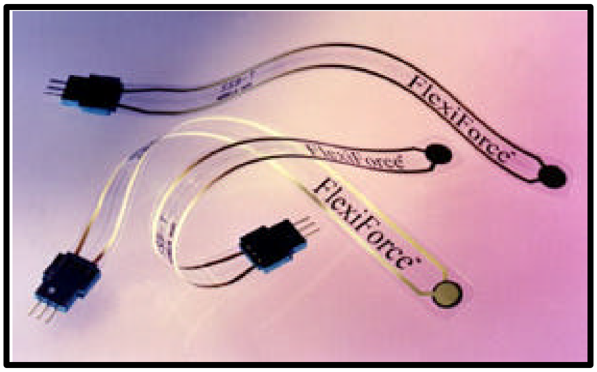


Figure 3.4 Flexiforce Sensor From Tekscan

pin Berg Clincher connector, which allows them to be incorporated into a circuit.

Force applied to the active sensing area causes in a change in the resistance of the sensing element; inverse proportional to the force applied. When the sensor is unloaded, its resistance is very high, and, when a force is applied, the resistance decreases.

3.3.4 Sensor Keyboard Installation

The SSB-T sensor was installed by sandwiching top and bottom sensors between a keycap and a force puck. The force puck was added to concentrate the force applied with the fingertip within the sensing area of the SSB-T. Prior to the installation of the sensor, the surface of the keycap was initially leveled by placing resin in its well, so as to have a flat, smooth surface. Next, a 1" x 1/8" slit was carved on the keyboard shell to connect the sensor flat wire to the electronic circuit inside the keyboard unit. Since the keyboard was retrofitted with the SSB-T sensors, it was necessary to isolate the key switch (Figure 3.5). Therefore, the copper clad traces connected to the switches were cut out, and wires were soldered from the switches' terminals to the 25-female connector installed on the front of the keyboard shell

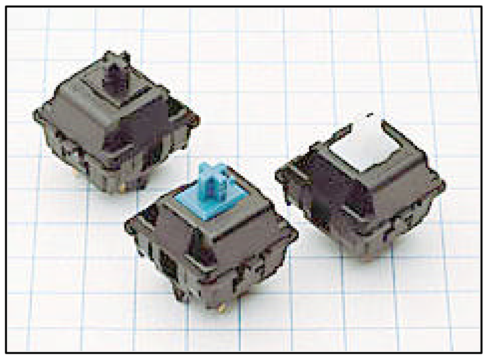


Figure 3.5 Keyboard Switches (no key cap).

(Figure 3.6).

3.3.5 Data acquisition card

The DAQ PI-MIO E card is a jumperless and switchless data acquisition board that uses the DAQ-STC as the system timing control. DAQ-STC is the backbone of the sensor system and the timing control application specific integrated circuit (ASIC). The DAQ-STC contains one 24-bit counter and three 16-bit counters. The counters are divided into three groups:

1. Analog Input--two 24-bit, two 16-bit counters
2. Analog output--three 24-bit, one 16-bit counters
3. General purpose counter/timer functions–two 24-bit counters

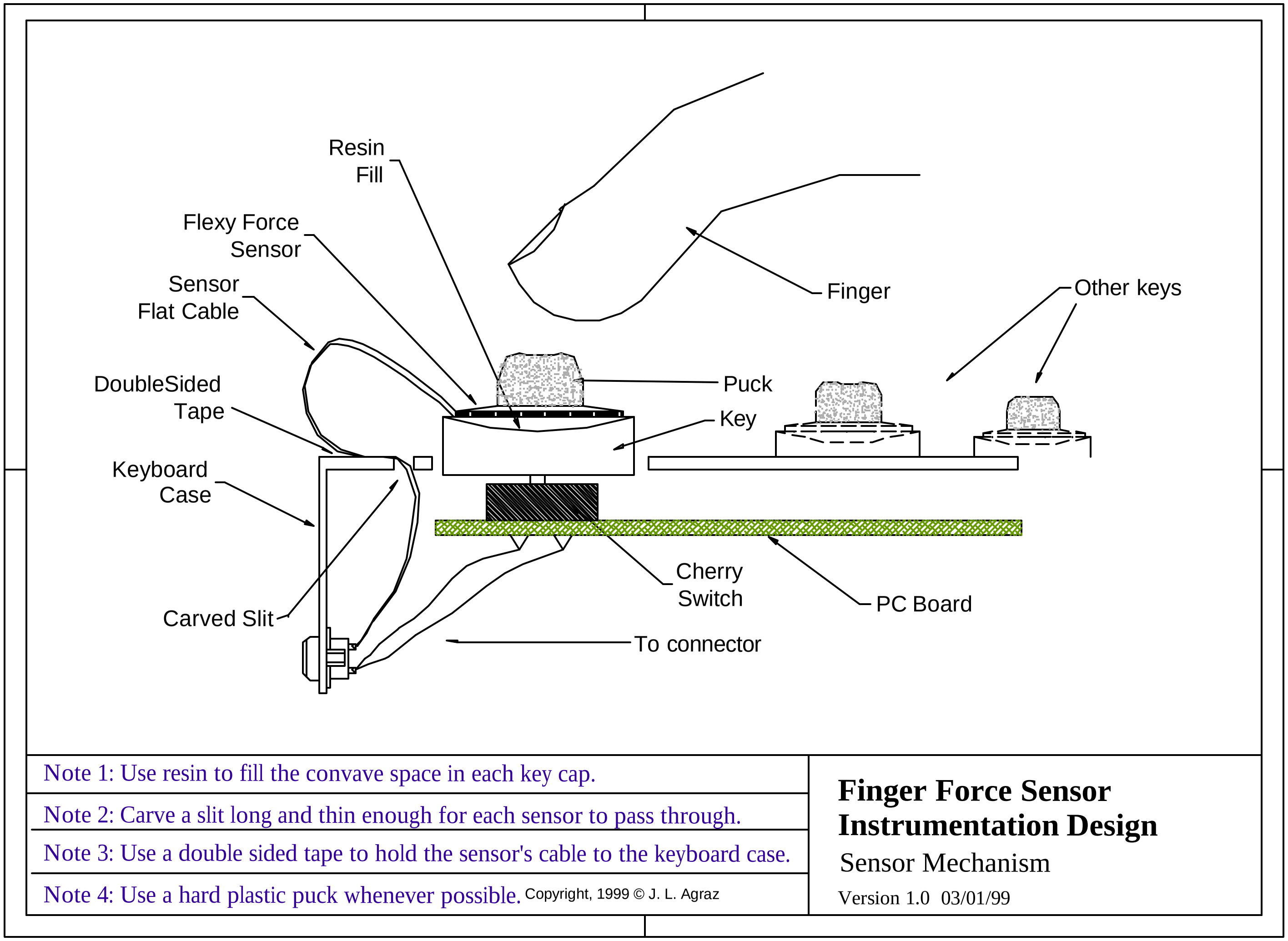


Figure 3.6. Detailed view of the retrofitted layout of the keyboard.

The board runs at a maximum speed of 250KHz and collects data using ten analog channels, five force channels and five switch channels. These channels operate at a sampling frequency of 1KHz using a non-referenced input setup to decrease noise induced in the instrumentation cables.

The board is set up in the following data collection mode: non-referenced single-ended (NRSE). A channel configured in NRSE mode uses one analog channel input line, which connects to the positive input of the Programmable Gain Instrumentation Amplifier (PGIA). The negative input of the PGIA connects to the analog input sense (AISENSE) connection (Figure 3.7).

3.3.6 Signal Conditioner and Power Supply Boxes

The signal conditioning hardware contains three main components;

1. Digital Conditioning Circuit
2. Analog conditioning Circuit
    - 5-Volts Ref
    - Preamplifier
    - Output Filter
3. Power Supply

Digital Conditioning Circuit. This circuit conditions the "on/off" switch position signal produced by the cherry switches in the keyboard (Figure 3.4), and supplies the signal to the DAQ card in the PC. The cherry switches in the keyboard are set to “high” using a pull-up resistor R_1, then a NOT gate U_1 (7404), which drives a Light Emitting Diode CR_1 (LED) and feeds the signal to the DAQ card in the PC.

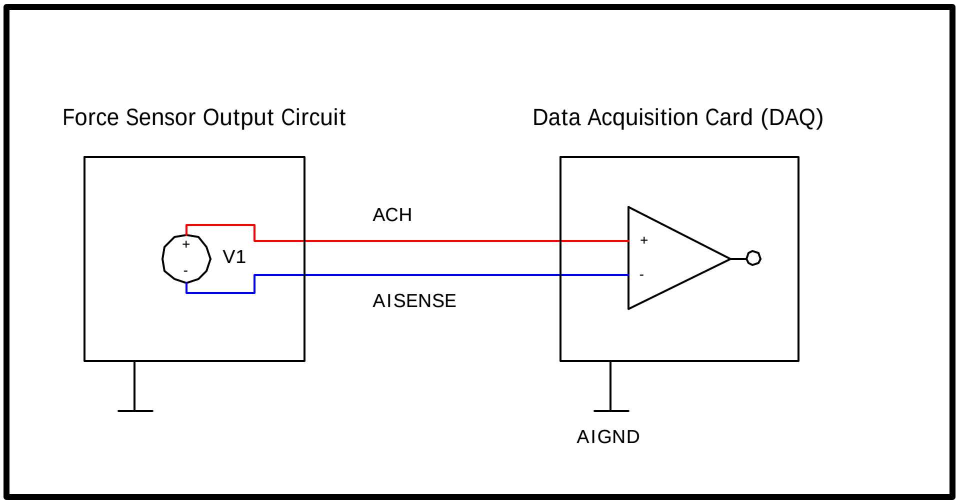


Figure 3.7 Sensor-DAQ non-referenced connection diagram.

The LED functions as part of a troubleshooting tool to detect any broken wires between the keyboard and the signal-conditioning enclosure (Figure 3.8). The LED turns off if the switch is pressed. If the LED stays on when the key is being pressed, then there must be a wiring problem in the system.

Analog Conditioning Circuit. This circuits condition the analog signals from the force sensors.

- 5-Volts Reference:This circuit is the first stage of the force-to-voltage converter (Figure 3.9). A steady voltage reference chip (Maxium MAX6250) is used as the excitation for SSB-T sensors. The MAX6250 is a low-noise, precision voltage reference with extremely low 1ppm/ºC-temperature coefficient and excellent ±0.02% initial accuracy.
- Preamplifier: The preamplifier circuit, along with the SSB-T sensor, was designed to convert force applied to the keys into an electrical signal. This circuit uses a low noise operational amplifier (Burr-Brown OP27) in a single-ended arrangement to

produce an analog output based on the SSB-T sensor resistance and a fixed reference resistance R_1. Also, the circuit includes a 10-turn potentiometer (R_2) as a signal-gain control that provides a better resolution during the gain-calibration procedures.

- Output Filter: The output filter circuit was designed to block high frequency noise picked up from the surroundings and produced by the circuit. The filter is composed of components R4 and C1 with a cutoff frequency of 63MHz. Also, the circuit includes an offset control composed of resistors R_6 and R_7, and a 10-turn potentiometer R_5 that provides a better resolution during the DC offset calibration procedures.

Power Supply. The power supply enclosure contains a ±12V supply that powers the analog components and a +5V supply that powers the transistor-transistor logic (TTL) components.

3.3.7 Key Force Calibrator

In order to test the linearity of each SSB-T sensor, a calibrator was constructed to provide a wide range of forces that could be compared to the voltage output of the circuit (Figure 3.9). This device consisted of a rectangular platform which had two levels attached to its surface. Attached to the platform was a 4-inch brass bolt that was held in placed over each key by two micromanipulators. Weights were placed on top of the platform and corresponding voltages recorded (Figure 3.10).

The calibrator was positioned on top of the keycap puck (Figure 3.11). To insure that a straight-down force was exerted on the keycaps by the calibrator, both

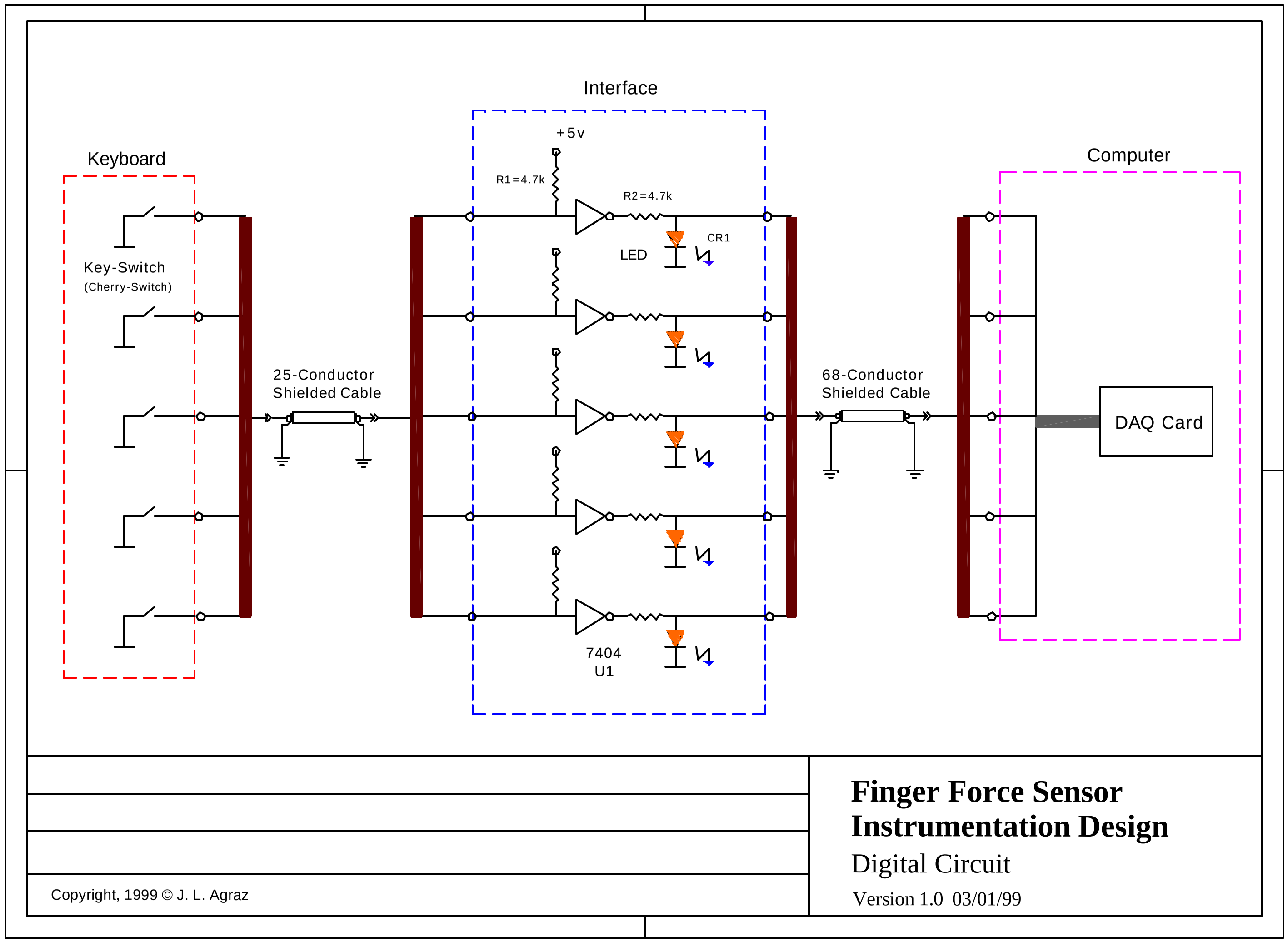


Figure 3.8. Digital Conditioning Circuit.

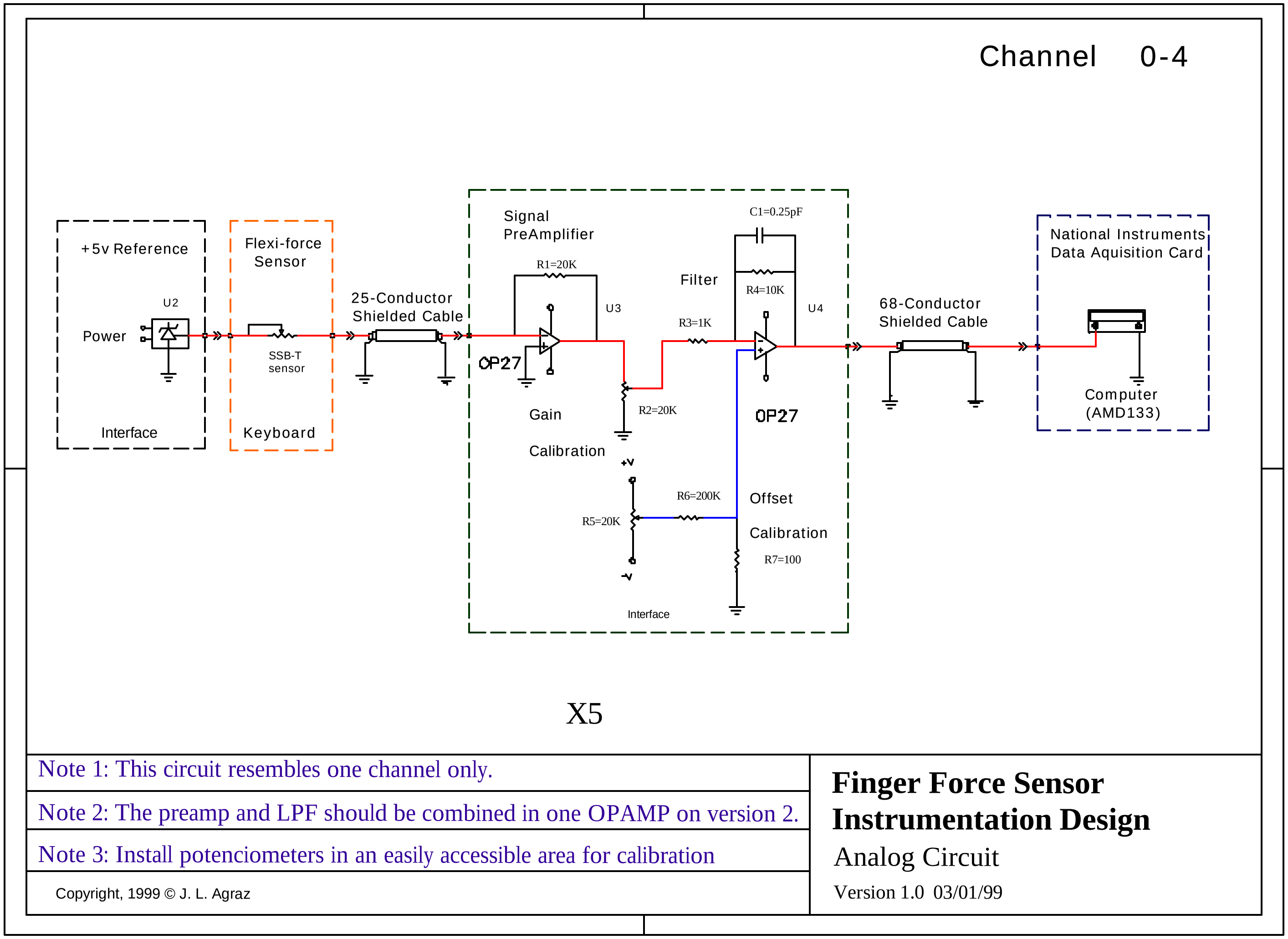


Figure 3.9. Analog Conditioning Circuit.

levels on top of the calibrator had to be level. Thus, a real force contrary to a complex force value would be applied to the SSB-T sensor. Lead weights up to the reported sensitivity of SSB-T sensors were placed incrementally according to their weight onto the rectangular platform and the corresponding voltages were recorded. Experiments using this mechanical fixture were repeated a minimum of three times on different days.

The output voltage data was then converted to Newtons using the formula:

$$F = ma \qquad (3.1)$$

Where:

F is the output force in Newtons

m is the total mass of the calibrator in Kilograms

a is the earth gravity in meters per second squared

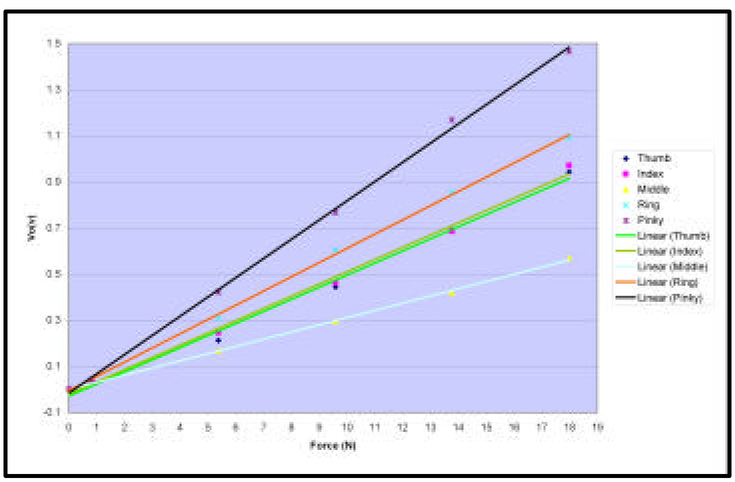


Figure 3.10. System calibration curves

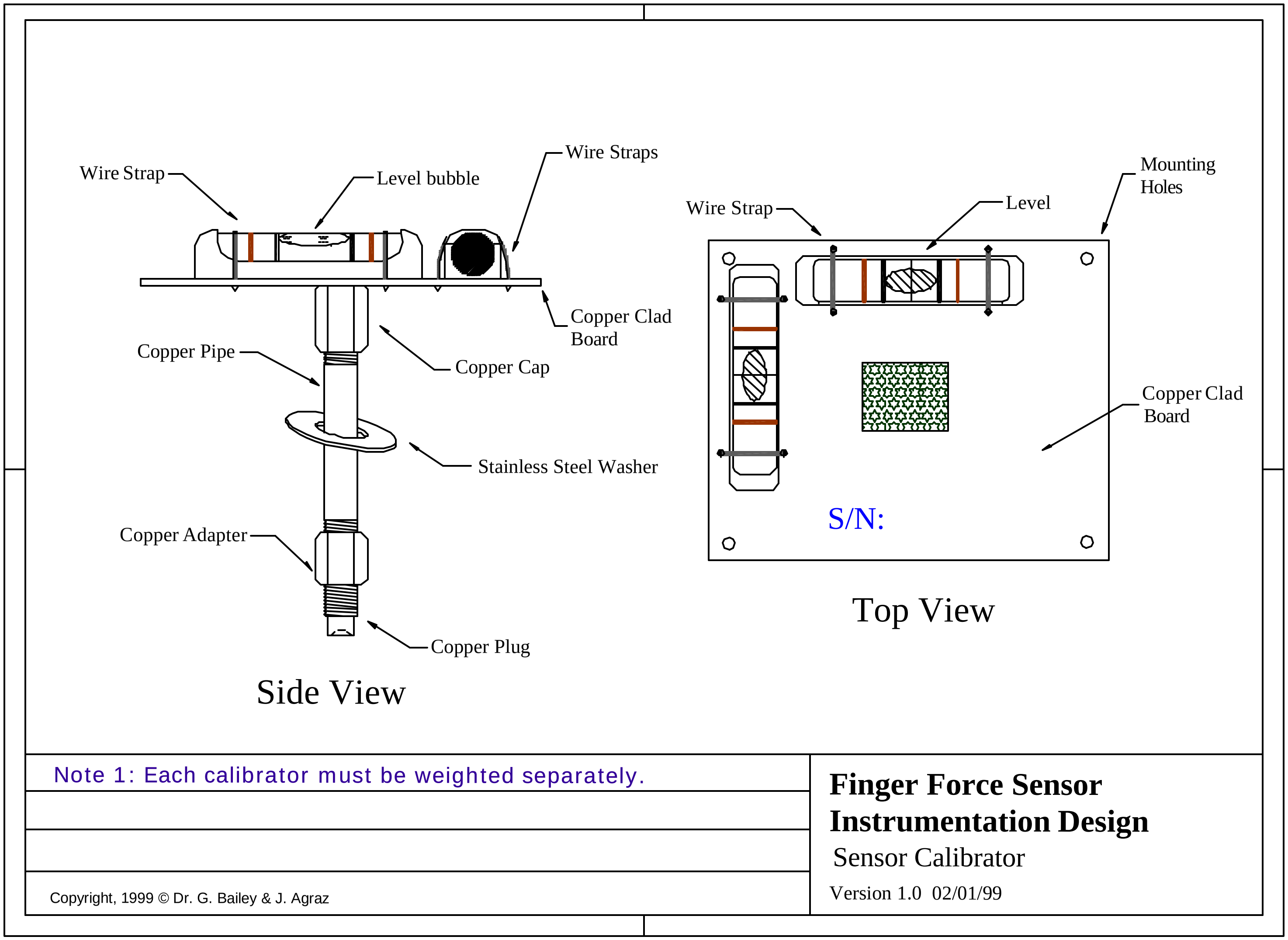


Figure 3.11. System sensor calibrator

3.4 Description of Software

The software collects information about each human subject. This database consists of; (1) calibration information from isometric exercises, (2) displays of the isometric force levels, and (3) force-data from the user, collected when typing on the BAT keyboard. In addition, the software generates plots of all force-data separately for each key.

The software component of this system was programmed using a graphical user interface (GUI) programming language called LabVIEW. The short learning curve and the capability of providing an exceptional user-friendly interface made this program language the best choice (Figure 3.12). The programming was done by the use of LabVIEW Sub Virtual Instruments (VI) (Figure 3.13), or procedures, as on text based programming languages as C, Assembly or Fortran.

The software goes into to a loop waiting for the user to click on any of the buttons on the screen (Figure 3.12, 3.13 and 3.14). Once the subject presses a button, the program executes the appropriate VIs.

In addition, the data-collection program uses an "ini" file that controls and stores the parameters within the program. Data stored includes; sampling frequency, calibration coefficients, isometric parameters, data file path, and initial sound and channel settings. The purpose of this feature is to decrease the amount of time required for the development of the system. When all the variables are stored in a single easy-to-access file, changes can easily be made to the program without recompilation. The program will search for the file "force.ini" containing the information previously described. This "force.ini" file is formatted according to

Windows "ini" file standard format such as labels (placed within square brackets) and items that follow immediately.

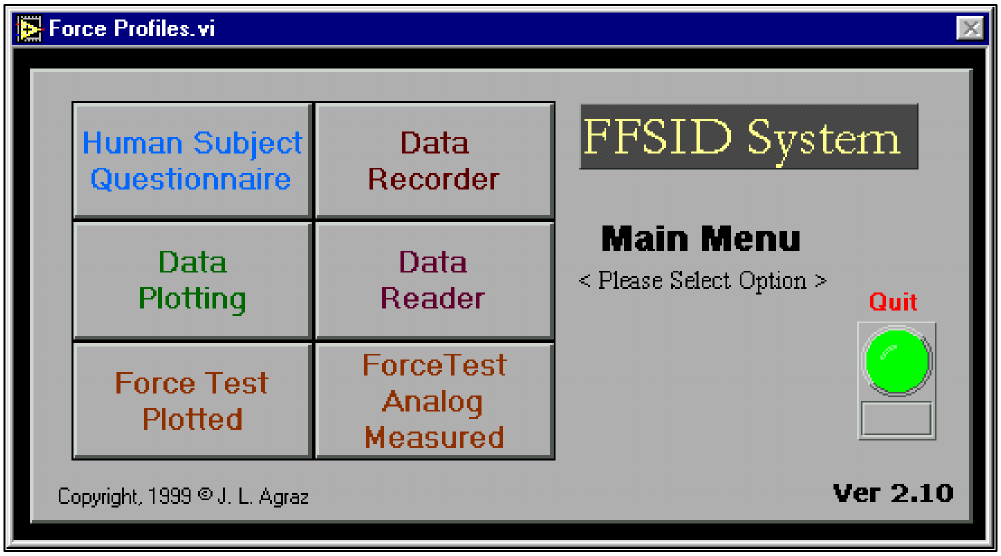


Figure 3 .12 Finger Force Sensor Instrumentation Software. Version 2.10

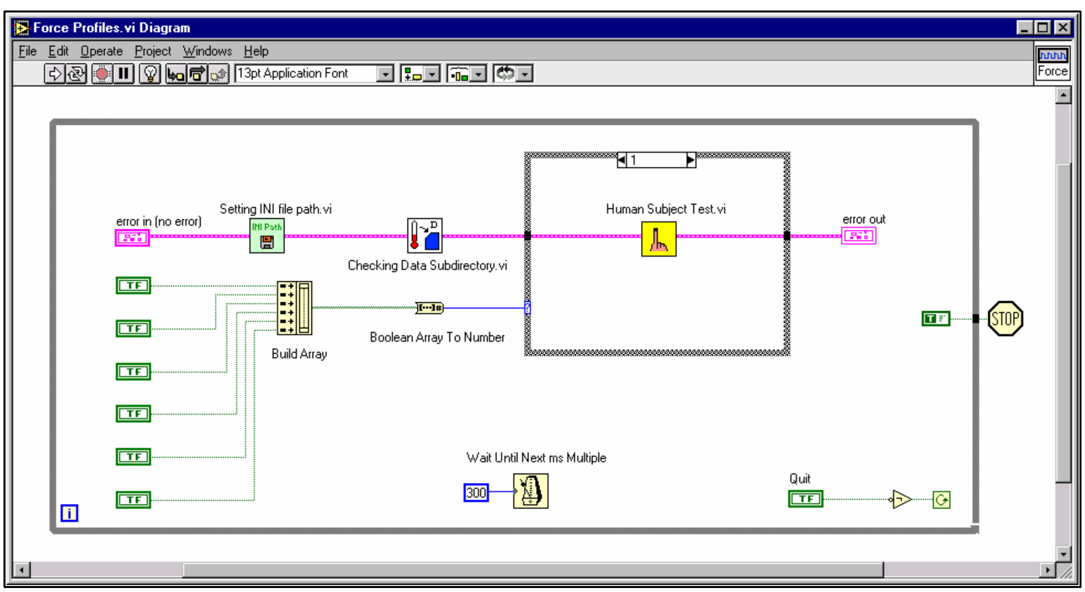


Figure 3.13 Finger Force Sensor Instrumentation Software code. Version 2.10

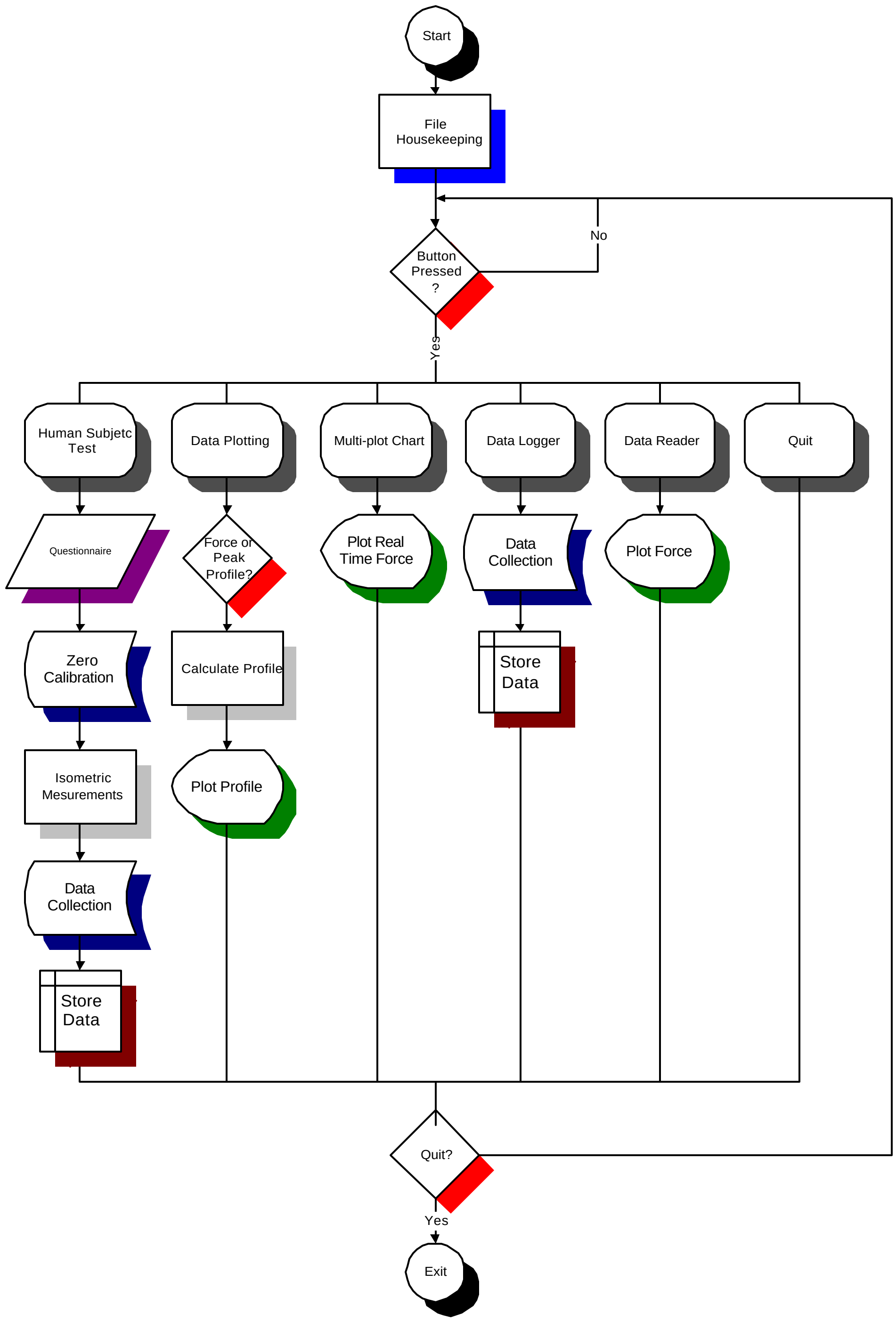
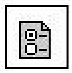


Figure 3.14 System Software Block Diagram

3.4.1 Main program virtual instrument icons

 **Human Subject Test.VI.** This VI (Figure 3.15) records the information from the human subject questionnaire, calibrates the system at zero force input, sets isometric parameters and records force data.

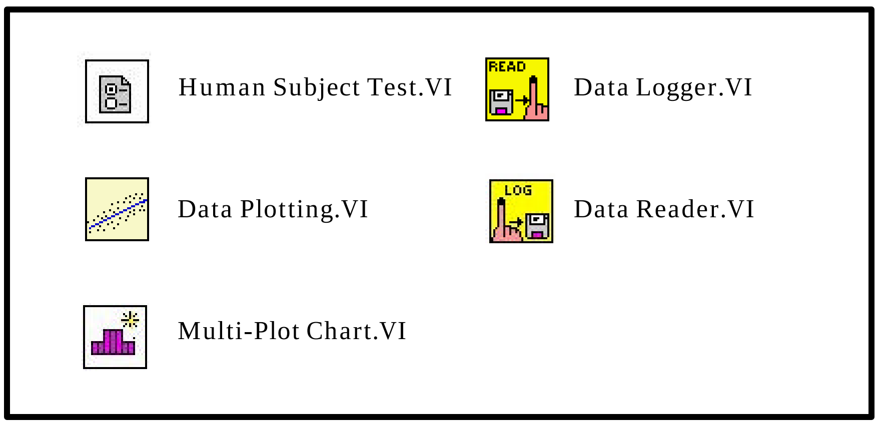


Figure 3.15 Software Icon code. Version 2.10

- **Human Subject Questionnaire:** (Appendix C)**:** The questionnaire, which was approved by the Human Use Committee, was used to maintain a permanent record of the subject's voluntary participation in this study. Thus, this electronic questionnaire stored all the subject's information, increased efficiency and reduced waste. Each set of user information is attached to the force data-file as a header (Figure 3.16).
- **Zero Force Input Calibration:** The system begins collecting data for one second at a sampling frequency of 1KHz. Then, using all the data collected, an average value is calculated and stored in the "force.ini" file for future references, and also becomes part of the force data file header.

- **Isometric Parameter Setting:** The program will ask the human subject to use all five fingers at the same time and press on the keyboard keys as hard as possible; then, the VI calculates the isometric target force by using 80% (as stated in the "force.ini" file), the subject's maximum force value for each finger.

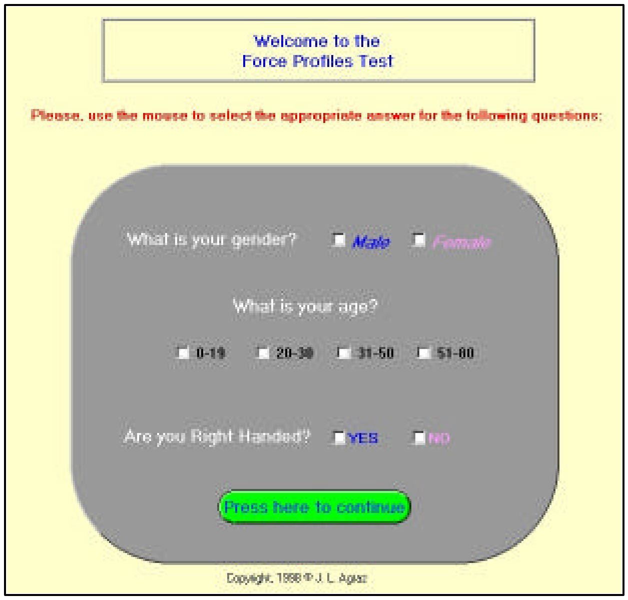
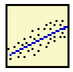


Figure 3.16 Human Subject first set of questions

- **Force Data:** After the isometric parameters have been established, data collection begins. The force data is sampled at 1KHz, and collected in small blocks of 50 samples. These collected samples are stored in a 9K bytes buffer for later retrieval. The number of block samples collected at one time was selected as a trade-off between accurate screen refreshment and a reliable data collection, without overflowing the buffer and crashing the program. However, there are other set of numbers that will work equally as well, depending on the computer hardware and speed.



Data Plotting Menu.VI: The data-plotting menu displays a peak-force per repetition and a linear curve fit that forms a human subject profile (Figure 3.17). The plotting of the force profile for a single or all fingers is done by first stripping the human subject information from the data file header. The binary data stored in the data file is converted to an ASCII format and pottered on the screen. The user has the option of changing several parameters of the plot such as: color, scales, line style, point style, plot type, and interpolation. In addition, the VI displays a set of markers that shows when the switch closes and opens for every key. The VI gives the user the option of selecting a peak-force profile. This profile is the result of the calculation of a peak force for every key-strike and has the same plotting features as the force profiles above.

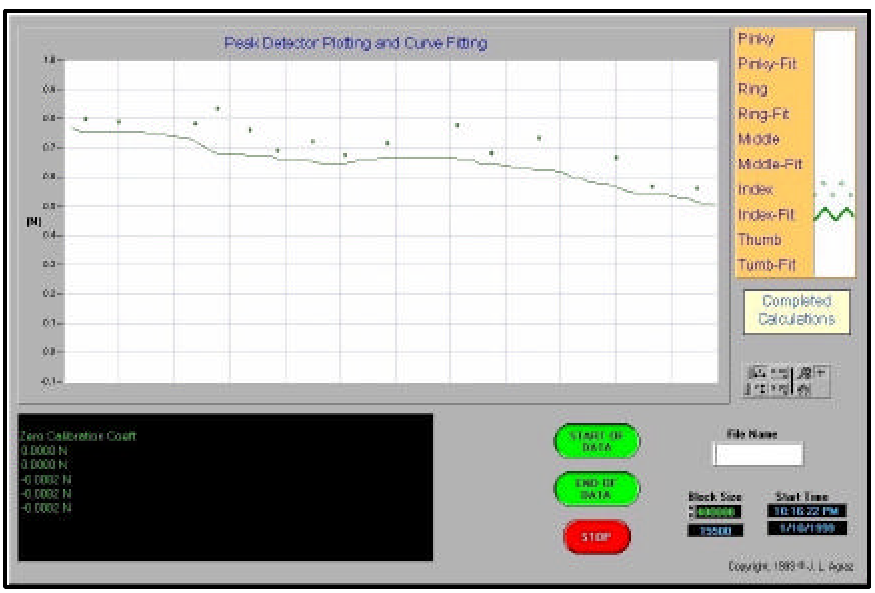
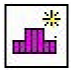


Figure 3.17 Finger Force Plot Sample Screen.



Multi-Plot Chart.VI: This VI is used as a troubleshooting tool to test each separate channel of the data collection system. The VI collects data in a real-time mode using a sampling rate of 1KHz in blocks of 50 samples, and displays the data point for each finger in separate plots. It's used mainly for troubleshooting purposes, because the development of the system began using many different force sensors (Figure 3.18). Also, this VI has the feature of calibrating the output of the system for zero input and storing the zero calibration data in the "**force.ini**" file.

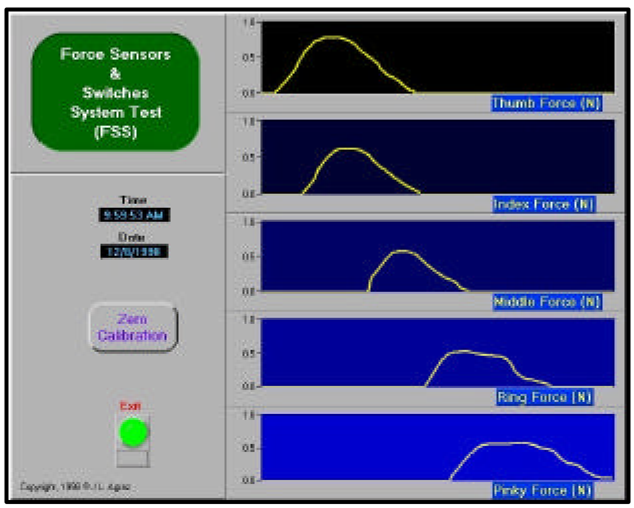


Figure 3.18 Finger Force Plot Chart

Data Logger.VI: This VI quickly begins data collection without having to fill out an electronic human subject questionnaire. However, the VI uses isometric targets setup in advance in the "**force.ini**" file. The purpose of this VI is to provide the user with a fast way to collect data from a human subject for trial purposes. In addition, the VI displays the current force being exerted on the keys by means of a set of blue color bars (Figure 3.19). Also, the VI displays the date, time and sampling frequency being used. The recording of the data is at a sampling rate of 1KHz in blocks of 40 samples that update the force bars on the on the VI's front panel. These parameters are also specified in the "**force.ini**" file. The data is recorded in a binary file named "**binary.dat**" and is stored in the computer's hard disk.

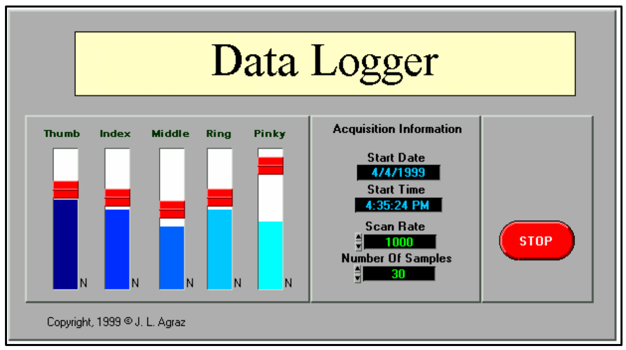
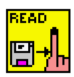


Figure 3.19 System data logger.



Data Reader.VI: This VI displays the force data recorded for all fingers by previous VIs as the Data Logger.VI and the human Subject Test.VI. The front panel displays all the human subject information previously recorded (if any), and allows the user to navigate through the data file by means of sets of data blocks (Figure 3.20). Each block is composed of a number of data points that could by controlled by the user through the Block Size control. Also, the VI's graph contains a palette that allows the user to zoom in and out of a waveform and allows complete control over the X and Y scales.

3.5 Human Subject Testing

The objective of this study deals with the development of systems that can easily and accurately measure the generation of sequential finger-force. Limited experimentation was conducted using students at San Diego State University

(SDSU) to evaluate the applicability of the system. Human volunteers used the sequential finger force system. Initially, subjects were required to depress the key in time to a metronome set at 1 stroke per second. This test evaluated the reliability and durability of the device. Subjects were seated comfortably and the sequential finger force-measuring device was placed so that their right elbow would form a right angle with the humorous bone. A second set of experiments consisted of the subjects depressing the index key in a typing motion until the onset of fatigue.

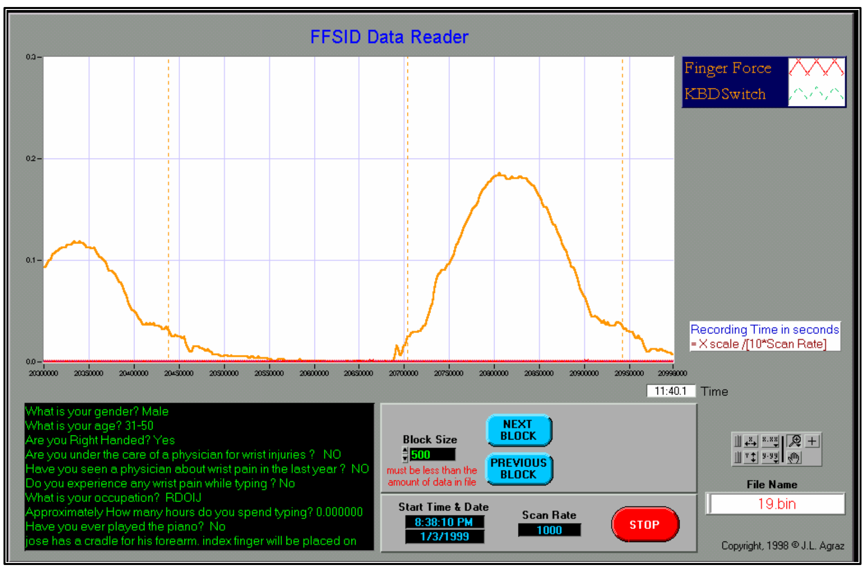


Figure 3.20 System data reader plot

CHAPTER 4

PILOT STUDY

4.1 Pilot Study Goals

The goals of the pilot study were to test the operation of the hardware and software, to determine the usefulness of the system and to tests the effectiveness of the apparatus in producing force profiles for future research.

4.2 Experimental Design

4.2.1 Variables Studied

In an effort to limit the number of variables tested during the pilot study, an ergonomically efficient keyboard was used. In addition, a wrist brace was used to limit the motion of the wrist. Also, Velcro was used to attach the wrist brace to the keyboard and to keep the wrist from moving while resting the hand on the keyboard.

Each human subject was asked to use the index finger from the right hand to tap on to the keyboard key repetitively until the onset of fatigue felt either in subject's arm and/or index finger (Figure 4.1).

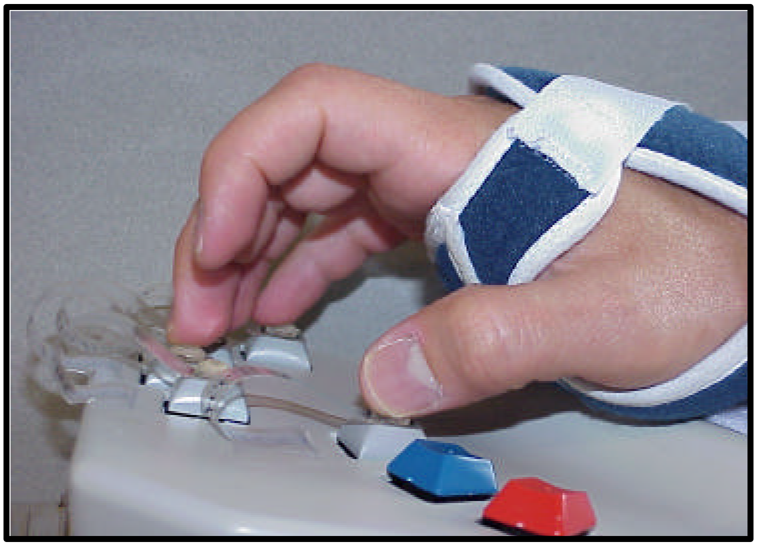


Figure 4.1. Human Subject Hand Being Tested.

4.2.2 Experimental Protocol

In order to compare human subject's finger-force profiles, the following test procedure was consistently used for each test session:

1. An explanation about the purpose of the research was given to the subject, followed by the description of the possible applications of the study's findings. The subject was then told what to expect in the experiment and asked to read and sign an informed consent form.
2. An oral review was given about the test procedures, with a demonstration of finger and hand positioning.
3. The subject was fitted with the wrist brace and helped to position the index finger and wrist on the keyboard.
4. After the subject felt confident and had practice fairly well, the actual test began.

5. The subject was asked to fill the electronic human-subject questionnaire
6. The subject was asked to perform an isometric exercise on the keyboard to determine a target force
7. The subject was asked to type repetitively one key using the index finger, until the onset of fatigue.
8. At the conclusion of the test session, the data was saved onto a data disk.

4.3 Recruitment of Subjects

All ten subjects of mixed gender, ranging in ages from 21 to 40 years, were San Diego State University electrical engineering students (geeks). They were each asked to read and sign a consent form and participated in the pilot test that lasted an average of 15 minutes. Subsequently, they were given a gift certificate to acknowledge their participation.

4.4 Human Subject Testing

The objective of this study deals with the development of a system that can easily and accurately measures the generation of sequential finger-force. Limited experimentation was conducted using students at San Diego State University (SDSU) to evaluate the applicability of the system. Human volunteers used the sequential finger force system. Initially, subjects were required to depress the key in time to a metronome set at 1 stroke per second. This test evaluated the reliability and durability of the device. Subjects were seated comfortably and the sequential finger force-measuring device was placed so that their right elbow would form a right angle. A second set of experiments consisted of the subjects sequentially depressing all the keys. Subjects were requested to depress each key separately and continue until they felt fatigued.

CHAPTER 5

ANALYSIS OF RESULTS

The analysis of the force data was performed off line by the Force Peak Search Analysis Program developed exclusively for this project. This program reads the force data recorded previously and selects the maximum force value for each repetition. Then, using these new force values, the program creates an ASCII file easily readable by other analysis software such as SPSS. The analysis of variance (ANOVA) test was performed on the individual subject averages using a statistical software package, SPSS 7.5 for Windows.

5.1 Statistical Analysis of Performance Report

The average of the first 25 repetitions of the force applied for all 30 subjects are shown in table 5.1 and histogram (Figure 5.1). Note that the mean force is 0.25 N.

Additionally, the averages of the last 25 repetitions of the force applied by the same 30 subjects are shown in table 5.2 and histogram (Figure 5.2). Note that the mean force is 0.25, which is the same mean force as the first 25 repetitions.

It was hypothesized that because of the fatigue of the individual subject, the force level applied during the last 25 repetitions would be significantly less than the force applied during the first 25 repetitions.

Table 5.1 First 25 Repetitions Test Results

Statistics: Average of First 25 Repetitions							
N		Mean	Median	Std. Deviation	Minimum	Maximum
Valid	Missing					
30	0	0.25308	0.19400	0.15602	0.072	0.708

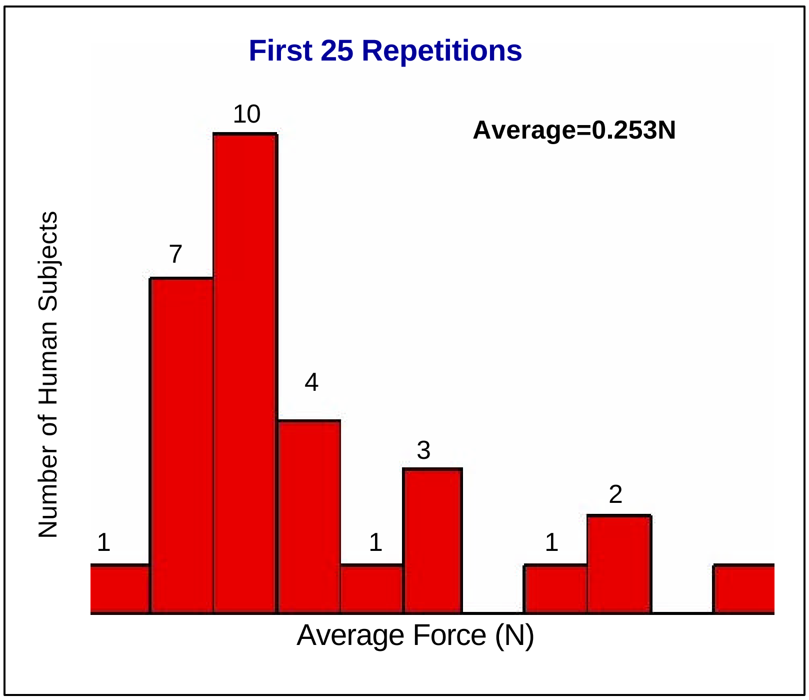


Figure 5.1. Human Subject's Mean Forces Histogram For The First 25 Repetitions

Table 5.2 Last 25 Repetitions Test Results

Statistics: Average of Last 25 Repetitions							
N		Mean	Median	Std. Deviation	Minimum	Maximum
Valid	Missing					
30	0	0.25204	0.21250	0.13729	0.013	0.547

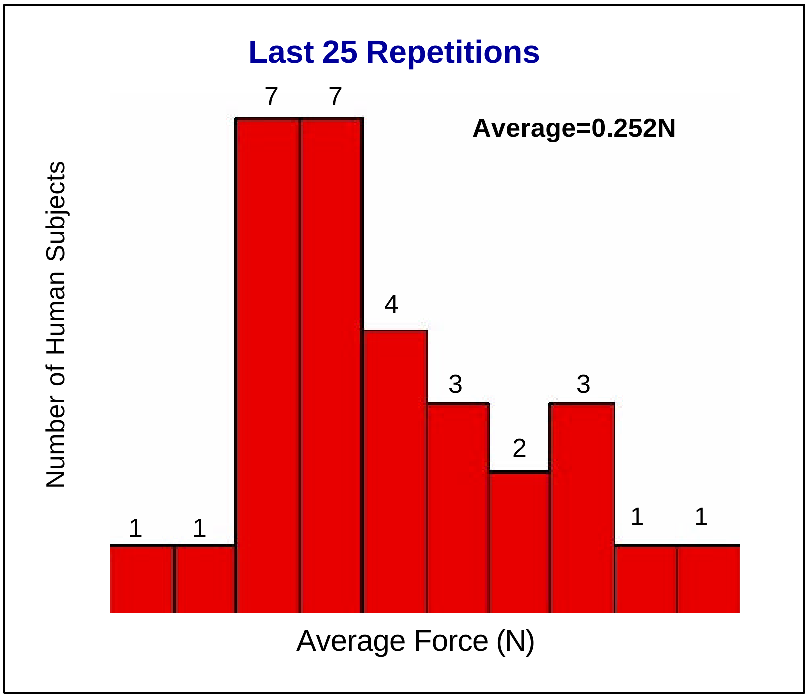


Figure 5.2 Human Subject's Mean Forces Histogram For The Last 25 Repetitions

Ha: Force applied during the last 25 repetitions would be significantly less than the force applied during the first 25 repetitions.

To test this hypothesis an Analysis of Variance (ANOVA) test was performed on the individual subject averages using SPSS 7.5 for windows, a statistic software package for the personal computer. The sources of variance used in the analysis were the first 25 repetition force averages and the last 25 repetition force averages of all 30 subjects. The sources of variance were analyzed to determine whether fatigue (last 25 repetitions) has any significant influence on the force applied.

The result of the analyses using ANOVA is shown in table 5.3. The fatigue level (last 25 repetitions) that was hoped to have a significant effect upon the subjects' force level was found not to be statistically significant in the ANOVA test. Significance was defined as having a ***p*** level less then 0.5N, but the ANOVA test had a ***Sig***. of 0.152N.

5.2 Pilot study conclusions and discussion

As previously mentioned in preceding chapters, the goal of the pilot study was to test the operation of the hardware and software and the usefulness of the testing apparatus. The second goal was to collect some useful information about fatigue from typing.

Table 5.3 ANOVA Test Results

ANOVA Table							
			Sum of Squares	df	Mean Square	F	Sig.
Average of First 25 Repetitions * Average of Last 25 Repetitions	Between Groups	(Combined)	0.697	27	0.026	6.011	0.152
	Within Groups		0.009	2	0.004		
	Total		0.706	29			

Although, it was logical to hypothesize that the fatigue would influence the force level applied by the subjects, the result from the test revealed no statistically significant findings.

The differing learning abilities of the subject may also indicate that a single five-minute test may be inadequate to effectively evaluate the subject's performance on the keyboard. In addition, none of the subjects conducted the experiment at the same rate. The use of an environment closely resembling a workplace by using a full size keyboard to the hardware may give results that would support the hypothesis.

In conclusion, this pilot study evaluated and confirmed the usefulness of the test apparatus. Force data was collected from 30 human subjects, which signal shapes concurred with a previous study from David Rempel [1]. In addition, this system provides a wide range of sampling rate (1KHz-250KHz), a much lower cost, and an 10 data collection channels; five force data and five digital data channels from the keyboard keys.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The results from this study indicate that future studies using this device could benefit from the following recommendations:

- A full size keyboard is needed to realistically test the force individuals use during typing on their daily jobs.
- In order to decrease the total cost of the system, the use of a microcontroller-based system would eliminate the need for a personal computer and an expensive DAQ card.
- A RF, or TCP/IP link from the force-measuring keyboard is needed, as is a central computer for analyzing the data.

6.1 Recommendations For Improving Individual Force Sensors

There are several improvements suggested for the system described in this paper. One of them is the relocation of the sensors to a place where the sensor doesn't have a direct contact with the outside world. In order to avoid wear and tear, it would be a good idea to place the sensors underneath the keycaps. However, care must be taken to avoid inaccurate force reading because of an indirect interaction from the fingers and/or the direct interaction of other hardware with the fingers.

6.2 Recommendations For Future Expansions

The use of a seven-key keyboard does not result in a truly accurate force profile. Although the results are very useful and interesting, the use of a full-size keyboard will more nearly resemble the daily force profiles produced while at the workplace. The development of a full-size keyboard will be a much better tool with which to analyze the force profiles of human subjects. In addition, the development of a complete software package system, performing data acquisition and real-time ANOVA analysis would be a great software improvement.

6.3 Summary

This system was proven to be very useful in the exploration of finger force over time. Also, the system proved rugged and flexible enough to accommodate fine-tuning changes on hardware and software, with a minimum of dead time during the pilot study.

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APPENDIX A

INFORM CONSENT AGREEMENT

SAN DIEGO STATE UNIVERSITY

Informed Consent Agreement
Finger Force Sensor instrumentation Design

You are being asked to participate in a research study. Before you give your consent to be a volunteer, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

Investigators: Jose Agraz, as graduate student and teacher aid in the electrical and computer-engineering department is the principal investigator for this study. He's currently working for the Naval Space Surveillance Station in Chula Vista, CA and plans to enhance his education with a Ph.D. in Bioengineering. For more information visit the web at http://kahuna.sdsu.edu/~agraz.

Co-Investigator: Professor Robert S. Pozos, Professor of Biology at the Department of Biology, San Diego State University is supervising this research bpozos@sciences.sdsu.edu.

Purpose of the Study: The proposed project seeks to study the correlation between force and electrical signals from your forearm muscle (EMG signals) during the finger depression and release of the keys on a computer keyboard. Based on these findings, the investigators will analyze, design, and develop an ergonomic eight key keyboard that will measure finger force and forearm EMG signals from a subject. It is hoped that this one-year project will result in the development of new techniques to minimize Carpal Tunnel syndrome injuries before they occur. Approximately 20 subjects who have no prior wrist injury will be recruited for this study.

Description of Study: You will be asked to perform a typical typing task on an eight key computer keyboard. This task will consists of using your fingers from your right hand to strike repetitively one key at a time at a certain force being displayed on the computer screen until fatigue sets in. At that time you may notify the researcher and you may pause for at least five minutes. To measure muscle response, six EMG electrodes will be placed on your forearm. The electrodes are composed of a two-sided fabric washer. One side is placed on your skin using a mild glue and the other side is attached to the EMG probe The frequency, force accuracy, and EMG signals from your forearm will be measured and recorded digitally on the computer's hard disk for later analysis. The test session will not last about 30 to 60 minutes.

What is Experimental in this Study: None of the procedures or questionnaires used in this study are experimental in nature. The only experimental aspect of this study is the collection of information for the purpose of subsequent analysis.

Risks or Discomforts: The risks associated with participation in this research are considered to be minimal. The use of an eight key computer keyboard may feel awkward to you. Also, the purpose of the experiment is to study finger fatigue, therefore, you may feel fatigue discomfort during and a few minutes after the test. However, should you begin to feel uncomfortable, you may immediately discontinue your participation either temporarily or permanently.

Benefits of the Study: The information collected from this research may contribute to society's knowledge regarding the causes and possible prevention of carpal tunnel syndrome injuries. The results of this research may also be used to develop safer and more ergonomically correct computer keyboards will reduce the incidence of these unnecessary injuries. It is not expected that you will benefit as a result of your participation in this research.

Confidentiality: Your performance on the assigned tasks and responses to a questionnaire will be reported only as part of a group. No individual information about any study participant will be reported. Small portions of the reordered data may be used to augment presentations at professional/scientific conferences at which results of the study are being described. Confidentiality will be maintained to the extent allowed by law.

Incentives to Participate: As an incentive to participate, you will receive a certificate for Starbucks coffeehouse (valued at about $2.00) following your test session.

Voluntary Nature of Participation: Participation in this study is voluntary. Your decision of whether or not to participate will not prejudice your future relations with SDSU. If you decide to participate, you are free to withdraw your consent and to discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

<u>Questions about the Study</u>: If you have any questions about the research now, please ask. If you have questions about the research, you may contact Jose L Agraz at 619-642-0170 jagraz@sciences.sdsu.edu, or Dr. R. Pozos at 594-2561 bpozos@sciences.sdsu.edu.

If you have any questions regarding your rights as a human subject and participant in this study, you may call the Committee on Protection of Human Subjects at SDSU for information. The telephone number of the Committee is 619-594-6622. You may also write the Committee at:

Committee on Protection of Human Subjects

San Diego State University

5500 Campanile Drive

San Diego, CA. 92182-1643

<u>Agreement</u>: The San Diego State University Committee on Protection of Human Subjects has approved this consent form as signified by the Committee's stamp. The consent form must be reviewed annually and expires on the date indicated on the stamp.

Your signature below indicates that you have read the information in this agreement and have had a chance to ask any questions you have about the study. Your signature also indicates that you agree to be in the study and have been told that you can change your mind and withdraw your consent to participate at any time. You have been given a copy of this agreement. You have been told that by signing this consent agreement you are not giving up any of your legal rights.

____

Name of Participant (please print)

____ ____________________

Signature of Participant Date

____ ____________________

Signature of Investigator Dat

APPENDIX B

COMMITTEE ON PROTECTION OF

HUMAN SUBJECTS (CPHS) PROTOCOL

Committee On Protection Of Human Subjects (CPHS) Protocol

Finger Force Sensor instrumentation Design

Abstract: The proposed project seeks to study the force signals from the human subject's index finger, during the finger depression and release of the keys on a computer keyboard. Based on these findings, the investigators will analyze, design, and develop an ergonomic eight key keyboard that will measure finger force signals from a subject. It is hoped that this one-year project will result in the development of new techniques to anticipate Carpal Tunnel syndrome injuries before they occur.

Purpose: In her written testimony to the U.S. House of Representatives Subcommittee on Workforce Protection Committee on Education and the Workforce, on May 21, 1997, Dr. L. Rosenstock, Director of NIOSH, stated that carpal tunnel syndrome (CTS) is the most widely spread type of the wrist muscular skeletal disorder (MSD) among computer operators and office workers. Although the exact cause of CTS, one of the most common nerve disorders, is poorly understood, it is believed that mechanical compression of the median nerve in the carpal tunnel with persistent nerve conduction impairment is the main cause for this disorder (Moore,1992). This view of CTS is supported by the increased incidence of MSD's and repetitive Stress Injuries (RSI) among workers performing highly repetitive jobs (i.e., jobs with a cycle time less than 30sec, or more than 50% of the time doing the same type of fundamental cycle).

Subjects: It is clear from the foregoing description that the participation of human subjects will be fundamental to this project. The human subjects will be invited to a campus lab (LS-336) in the Life Sciences Department and asked to type on a computer keyboard. This keyboard is an eight key ergonomically correct keyboard that will provide the user with the most comfortable position during the course of the study. The subject will be asked to continuously press and release a key using a single finger at a time until fatigue sets in.

Because the subjects' involvement will be limited to 30-60 minutes, repetitive stress injuries will be highly unlikely. In addition, an estimated number of 20 subjects will be required during the course of the one-year study. These subjects will be required to be within 20-30 years old and without any type of wrist injuries.
Other than maintaining confidentiality, persons in this study are expected to encounter very little potential risk to the physical well-being.

Methods: As stated above, the study design will require 20 subjects. These subjects must be between the ages of 20-30 years old, 50% of the subject pool will be females, never have had wrist injuries and willing to spend 30-60 minutes that the study requires. The data for each subject will be collected through an experimental and ergonomically correct force-sensing keyboard. The device will be connected to a personal computer (PC) that will coordinate and store all the data collected. Recruitment of subjects will be via word of mouth and a flyer posted throughout the San Diego State Campus. The location of the study will be in Life Sciences laboratory room 336.

The study for each subject will be conducted as follows:

The subject will be given a consent form to read and sign.

The subject will be given a questionnaire to determine his/her qualifications for this study. If the subject does not meet the requirements listed above, he/she will be dismissed.

The subject's right hand will be placed on the keyboard strapped with a wrist brace purchased at San Diego State University Health Services.

The subject will be asked to repetitively strike a keyboard key using his/her index finger to a pressure displayed on the computer keyboard. Once the target pressure has been reached, the subject will hear a tone. The subject will continue striking the key at the same rhythm until fatigue sets in.

Potential Benefits: Potential benefits for the study participants will be limited. However, the subjects will likely become more aware of hand positions that are more comfortable. As a result, one would expect the study participants to more routinely practice ergonomically sounder typing postures. Becoming more aware of good posture and proper support of the wrist are two modest potential benefits of participation in this study.

Potential benefits to the general population will likely be greater due to increased knowledge regarding the causes and prevention of MSD's and RSI's. It is also hoped that the development of safer and more ergonomically sound keyboards will reduce the incidence of these unnecessary injuries.

Potential Risks: Potential risks (psychological, social, physical, economic, legal, etc.) are minimal in the proposed study. As briefly described above, this type of laboratory experimentation will neither be dangerous nor prolonged. No effort will be made to deceive or mislead any of the subjects. Any relevant questions will be answered straightforwardly.

Precautions: The study will not require personal data from the subject pool. Therefore, there are no privacy issues with which to be concerned.

Compensation: The proposed budget has funds to pay the subjects for their cooperation with two $2 gift certificates for Creative Juices or AMC movie theaters.

Academic Background of Investigators: Jose L. Agraz is a graduate and teacher aid at the electrical and computer engineering department with an emphasis in bioengineering. As an undergraduate he has conducted research at the Idaho National Laboratory in Idaho Falls, Idaho and at San Diego State University. He's currently working for the Naval Space Surveillance Station in Chula Vista, CA and plans to enhance his education with a Ph.D. in Bioengineering.
For more information visit the web at

http://kahuna.sdsu.edu/~agraz

Investigator: Professor Robert S. Pozos, Professor of Biology at the Department of Biology, San Diego State University. He has served as Professor and Chair of Physiology at the University of Minnesota Medical School in Duluth, as Vice President for Research at the University of Washington in Seattle, and recently as

Director of the Physiological Performance and Operational Medicine Laboratory at the Naval Health Research Center in San Diego. bpozos@sciences.sdsu.edu

References (additional references are listed in the biographies of the investigators)

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APPENDIX C

SUBJECT QUESTIONNAIRE

Subject Questionnaire

The collection of this information was made on line using a graphical user interface and stored in digital form as a header on a data file for every human subject.

What Is Your Gender? ☐Male ☐Female

What Is Your Age? ☐0-19 ☐20-30 ☐31-50 ☐51-80

Are You Right Handed? ☐Yes ☐No

Are You Under The Care Of A Physician For Wrist Injuries? ☐Yes ☐No

Have You Seen A Physician About Wrist Pain In The Last Year? ☐Yes ☐No

Do You Experience Any Wrist Pain While Typing? ☐Yes ☐No

What Is Your Occupation? ______________________________________

Approximately How Many Hours Do You Spend Typing (Hr/Day)?_______________

Have You Ever Played The Piano? ☐Yes ☐No

When Did You Start Playing The Piano? ☐Yes ☐No

Approximately How Many For How Long? ☐Yes ☐No

Have Completed The Consent Form? ☐Yes ☐No

Do you have any Questions? ☐Yes ☐No

APPENDIX D

HUMAN SUBJECT DATA

Human Subject Data

Human Subject	*Peak Mean Force (N)*	
	First 25	Last 25
1	0.19	0.15
2	0.28	0.20
3	0.07	0.10
4	0.35	0.38
5	0.40	0.49
6	0.13	0.01
7	0.24	0.21
8	0.23	0.33
9	0.22	0.14
10	0.71	0.46
11	0.56	0.47
12	0.18	0.20
13	0.27	0.38
14	0.15	0.12
15	0.19	0.20
16	0.11	0.09
17	0.14	0.24
18	0.16	0.32
19	0.19	0.21
20	0.59	0.55
21	0.11	0.09
22	0.21	0.32
23	0.18	0.26
24	0.12	0.19
25	0.15	0.21
26	0.22	0.24
27	0.40	0.14
28	0.47	0.47
29	0.16	0.12
30	0.19	0.24

ABSTRACT

ABSTRACT

The proposed project seeks to study the force signals from the human subject's index finger, during the finger depression and release of the keys on a computer keyboard. Based on these findings, the investigators will analyze, design, and develop an ergonomic eight key keyboard that will measure finger force signals from a subject. It is hoped that this one-year project will result in the development of new techniques to anticipate Carpal Tunnel syndrome injuries before they occur.