# The Application of Axiomatic Design Principals to a Wearable Sensor Glove for Pediatrics With Median Nerve Damage: A Case Study

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*Axiomatic Design is the process of using design axioms to evaluate how well a solution meets the needs of a problem. There are two main design axioms that are used to evaluate how well a solution solves the problem: the Independence Axiom and the Information Axiom. These design axioms provide a process to clearly assist engineers and designers by describing the prerequisites, tools, and principals to select a solution that solves the problem in the best possible way. This paper presents a case study on how axiomatic design is used to selected the best possible pressure, strain, and temperature sensors to design a wearable sensor glove for pediatrics with median nerve damage. Axiomatic design is discussed to provide the reader with some background information on how it can be used to evaluate ideas. Additionally, context is provided to discuss the clinical need for this medical device and describe the medical conditions children suffer from. The shortcomings of currently available commercial products are discussed and the design axioms are used to scientifically analyze their shortcomings. Alternative solutions are generated using a systematic analysis of the design problem and the optimal design alternative is identified for the three different sensor nodes.*

## Nomenclature

{FR} Functional Requirements
{DP} Design Parameters
{PV} Process Variables
{CA} Consumer Attributes
[A] Design Matrix
[B] Design Matrix for the Process
P Probability of Success
$L^{DR}$ Design Range
$L^{SR}$ System Range
$\Delta L$ Common Range
$I_i$ Information Content
$I_{min}$ Minimum Information Content

The above nomenclature is used to describe the variables used in the axiomatic design analysis. The definition of these variables are defined in the introduction and they will be used in various sections of this paper. The written description of the variable will be used in all paragraphs and the variable will be used in equations.

## 1 Introduction

To provide some background information to the reader, axiomatic design is described to highlight the techniques used to evaluate which design is the optimal design solution to the solve the given problem. These design principles govern the processes and methodologies used evaluate the proposed design solutions for these problems.

Next, background information is provided to discuss how nerve damage in children is evident and the sever ramifications that can result from the nerve damage. Additionally, the symptoms children exhibit when they have nerve damage are highlighted. Moving from there, the diagnosis steps taken by doctors is discussed. Although nerve damage in children is a broad category, the median nerve is focused highlighted as a primary focus of concentration. Therefore, the details of this nervous system are explained to give the reader an insight into how nerve damage in children affects their nervous system.

Current treatments are discussed to detail how the symptoms of nerve damage in children are dealt with to highlight the need for a medical device to solve the underlying problem. This conversation leads itself into what a wearable sensor glove is and how it can be used to measure the symptoms currently experienced by children. There are three different sensor nodes that are targeted by a wearable sensor glove for this applications and three commercial products are presented for each sensor node.

The design axioms are used to evaluate each commercial product. Next, the design parameters and process variables are detailed for each sensor node. Then alternative solutions are presented for each sensor node and axiomatic design is used to evaluate how successful each alternative design is used.

## 2 Review of Axiomatic Design

Axiomatic Design, AD, is a ”systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables.” An axiom, is defined as a ”self-evident truth or fundamental truth for which there is no counter examples or exceptions. It cannot be derived from other laws of nature or principles.” There are four domains to the design world: customer, functional, physical, and process. Each domain has a certain characteristic vectors and the interactive design process iterates from left to right as seen in Fig. 1.

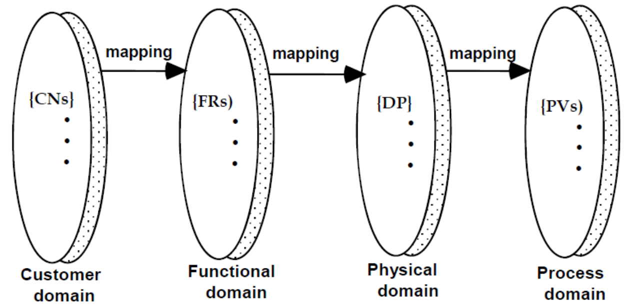


Fig. 1. Four Domains of the Design World [1]

The customer domain consists of the customer needs or customer attributes, $\{\mathrm{CA}\}$, which corresponds to the what the customer is looking for in a product. There are constraints that are used to bound acceptable solutions. There are two types of constraints: input constraints that are imposed as part of the design specifications and system constraints that are imposed by the system in which the design solution must function.

The functional domain consists of the functional requirements, $\{\mathrm{FR}\}$, which are defined as the engineering specifications and constraints. They are a ”minimum set of independent requirements that completely characterizes the functional needs of the product in the functional domain. By definition, each functional requirement is independent of every other functional requirement at the time that the functional requirements are established.”

These two domains, customer domain and functional domain, are tightly intertwined as the engineers and designers need to understand the customer needs, and they need to negotiate with the customers the technical feasibility of the product. These two domains can be grouped together to define the ”product definition” stage of development, as the engineering capabilities are defined in this stage. Sometimes, the back and forth nature between the two domains can be reflected through marketing and customer surveys, as the two groups compromise as they define the goal. Some of the problems detailed in this section are listed as contextual mismatching, ill-structured mapping process, and different market segmentation based on customer value. Additionally, this process must be completed in a "solution neutral" environment as not to constrain the creative thinking process.

The functional domain is used to define the physical domain, which consists of the key design parameters, $\{DP\}$, that satisfy the functional requirements. The design parameters are the "key physical or equivalent variables in the physical domain that characterize the design that satisfies the specified functional requirements." The transition from the functional domain to the physical domain is defined as the Product Design stage of development.

The process domain is used to define how the physical domain is implemented by defining the process variables, $\{PV\}$, that implement the design parameters. Additionally, the process variables are the "key variables in the process domain that characterizes the process that can generate the specified design parameters." The transition from the physical domain to the process domain is defined as the Process Design stage of development. The process domain consists of other design tools to combine the product variety with the process variety. This coordination between the material and operation can be detailed using a GBOMO, the combination of a generic bill of materials and bill of operations. However, this is outside the scope of this paper.

The two design axioms that can be used to evaluate the connection between multiple design domains are the Independence Axiom and the Information Axiom. The Independence Axiom maintains the independence of the functional requirements and maintains the Independence of ***fulfilling*** the functional requirements. The Information Axiom minimizes the information content of the design [1].

### 2.1 Independence Axiom

The Independence Axiom maintains the independence of the functional requirements, where the functional requirements are defined as the "minimum set of independent functional requirements that characterize the design goals."

The Independence Axiom can be applied to the relationship between the functional requirements and the design parameters. The functional requirements that define the specific design goals constitutes a vector, $\{FR\}$. Similarly, the design parameters in the physical domain that are derived from the functional requirements constitute a vector, $\{DP\}$. The relationship between the two can be shown in Eq. 1, Fig. 2, and Fig. 3.

$$\{FR\} = [A]\{DP\} \tag{1}$$

$$[A] = \begin{bmatrix} A11 & A12 & A13 \\ A21 & A22 & A23 \\ A31 & A32 & A33 \end{bmatrix} \qquad \{dFR\}=[A]\{dDP\} \qquad Aij = \partial FRi / \partial DPj$$

Fig. 2. Design Matrix Relationship [1]

$$FR_i = A_{ij}\, DP_j$$

$$\begin{aligned} FR1 &= A11\ DP1 + A12\ DP2 + A13\ DP3 \\ FR2 &= A21\ DP1 + A22\ DP2 + A23\ DP3 \\ FR3 &= A31\ DP1 + A32\ DP2 + A33\ DP3 \end{aligned}$$

Fig. 3. Design Matrix Linear Relationship [1]

One can see that Eq. 1, Fig. 2, and Fig. 3 detail the relationship between the functional requirements and design parameters. When the entrepreneur, marketers, or business manager defines the functional requirements, the engineer and designer can verify the design parameters meet the functional parameters using the above relationships.

Additionally, this relationship can be applied to the product design stage of development, as the design parameters can be used to create the process variables. This relationship can be shown using Eq. 2.

$$\{DP\} = [B]\{PV\} \tag{2}$$

When the designer or entrepreneur defines the design parameters and the manufacturing engineer or supplier defines the process variables, both sides can verify the process variables meet the required design parameters using Eq. 2.

Once both vectors are established, the design matrix can be evaluated to determine whether the design parameters meet the functional requirements. There are three categories to classify the design matrix: uncoupled, decoupled, and coupled design. The design matrix looks like the following representations in Fig. 4.

*Uncoupled Design*

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

*Decoupled Design*

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ A_{21} & A_{22} & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

*Coupled Design*

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix}$$

Fig. 4. Design Matrix Result Categories [1]

To satisfy the Independence Axiom, the design matrix needs to be defined either as an uncoupled design (diagonal matrix) or decoupled design (triangular matrix). When the design matrix is an uncoupled design, each functional requirement can be satisfied independently using one design parameter. Whereas, when the design matrix is a decoupled design, ”the independence of the functional requirements can be guaranteed if and only if the design parameters are changed in a proper sequence.” When the design matrix is a coupled design, each design parameter does not independently satisfy each functional requirement. Therefore, the design parameters are not optimized to meet the functional requirements. The subsequent analysis will only apply the Independence Axiom to the conversion from the functional requirements to design parameters.

## 2.2 Information Axiom

The second axiom, the Information Axiom, provides a quantitative means of measuring the merits of a give design, which can be used to select the best design among those that are acceptable. ”It provides the theoretical basis for design optimization and robust design. The axiom characterizes the content and complexity of a design.” ”In information theory, entropy is the average amount of information contained in each message received.” Therefore ”the information content is defined in terms of probability and the design that has the highest probability of success is the best design.”

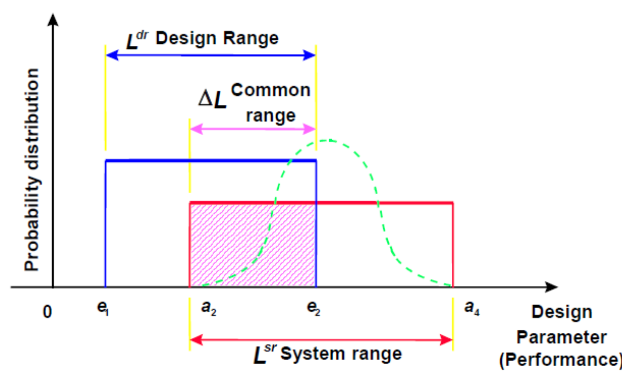


Fig. 5. Information Axiom: Probability Distribution [1]

Fig. 5 highlights how a normalized probability curve is used to calculate the probability of success between normalized variables. The system range, $L^{SR}$, is the ”capacity of a design parameter able to achieve in terms of tolerance.” The design range, $L^{DR}$, is the tolerance associated with a functional requirement expected by the customer. The common range, $\Delta L$, is the overlap area between the system range and the design range. When the system range is contained within the design range, the design specifications are satisfied 100% of the time. When there is only a partial overlap, the information content is calculated using Eq. 3. Where the Common Range is the area of overlap, and the System Range is the area under the system range curve.

$$I = log_2\left(\frac{L^{SR}}{\Delta L}\right) \quad (3)$$

When several design alternatives are available, the best design is the one with the minimum information content. When the information content, I, is equal to 0, then the design range and the system range completely overlap. When the design range and system range do not overlap at all, hen the information content is equal to .

The best design is identified as having the minimum total information content summed over all of its functional requirements or design parameters. This relationship is shown in Eq. 4.

$$I_{min} = \sum_{i=1}^{n} I_i \quad (4)$$

## 3 Background Information

### 3.1 Nerve Damage in Children

There are children in this world who are either born with or have developed peripheral neuropathy. Peripheral neuropathy occurs when there is a problem with the peripheral nervous system; "the network of nerves that transmits information from the central nervous system (the brain and spinal cord) to the rest of the body." Peripheral neuropathy can be caused by some of the following reasons: "certain diseases like shingles, hormonal imbalance, trauma or tissue injury, diabetes, extended periods of sedentary life, extensive pressure on nerves, or it can be caused by poor nutrition or exposure to toxins [2]."

The symptoms of peripheral neuropathy vary depending upon what nerves are affected and sometimes peripheral neuropathy is hard to diagnose. Children can experience the following symptoms: "pain, burning or tingling in hands or feet, muscle cramps or muscle twitching, or numbness or loss of sensation in arms and legs" [2].

Fig. 6. Dermatophagia in Children [3]

Peripheral neuropathy can cause self-abusive behavior, such as dermatophagia, as shown in Fig. 6. This behavior "was observed in two children with acquired peripheral nerve dysfunction. In one case a laceration over the median nerve was followed by self-induced trauma to the fingers distal to the cut, while the other patient developed self-mutilation in all the extremities following insecticide poisoning and presented with signs of diffuse peripheral neuropathy" [4].

Additionally, peripheral neuropathy can be caused through injury to the brachial plexus. Brachial plexus injury in adults commonly produces persistent pain, however this is difficult to determine in pre-verbal infants. Some of these young children self-mutilate the affected extremity, which may or may not reflect pain. A retrospective study was conducted by McCann et al. to characterize the clinical presentation and course of self-mutilation following perinatal brachial plexus injury. They identified 280 patients who had a perinatal brachial plexus injury from 1990 to 2002. They defined "self-mutilation behavior" as "excessive mouthing of or biting of any part of the affected limb, and/or loss of any parts of the affected limb secondary to biting and infection." From their identified population, eleven patients, 3.9%, demonstrated self-mutilating behavior and the median age of the onset of this behavior was 17 months. Additionally, the median onset of this behavior was 8 months after surgery and the median duration of this behavior lasted 6 months. The incidence of self-mutilation among children who had undergone surgery was 6.8% (9 of 133 children) compared to the 1.4% (2 of 147 children) for non-surgical patients ($P<0.05$). Seven of 24 children (29.1%) who underwent brachial plexus dissection demonstrated self-mutilation, which was significantly different from the incidence of self-mutilation in children who did not have surgery ($P<0.001$) [5].

As one can see, peripheral neuropathy is a very serious condition that can have drastically negative outcomes on the child's welfare. This condition must be diagnosed properly to ensure that root of the problem is identified to ensure self-abusive behavior does not continue.

### 3.2 Nerve Damage Diagnosis

To diagnose peripheral neuropathy, there are many different steps and tests that are performed to reach this conclusion. To begin, the child has a detailed physical exam and the child's past medical history and family history is examined. During the physical examination, the symptoms the child has experienced is documented. Also, the child's reflexes, muscle strength and tone, ability to feel certain sensations, posture and coordination are examined and noted.

Next, the doctors might order imaging tests, such as X-Rays, CT scans, or MRIs, to detect physical injuries, anatomical problems, and other conditions that could be affecting the child's nervous system.

Then, the doctors might suspect that the child may have an underlying autoimmune condition, metabolic disease or connective tissue disorder. These conditions and disorders can be detected by ordering additional blood tests and referring the child to specialists, such as a rheumatologist, endocrinologist or geneticist. Also, blood tests may be necessary to determine if the child has been exposed to toxins.

Finally, a nerve conduction exam will be performed to measure the signals from the targeted sensory nerves. The exam may include the following tests: mono-filament test, nerve conduction study, or an electromyography test. The mono-filament test is performed by the doctor who presses many different short pieces of filament against the child's skin in various places. These pieces of filament have various levels of stiffness. So, the doctor will apply a force on the child's skin through the filament. As the doctor increases the force on the filament, the force will be transferred through the filament until the force hits a maximum value that causes the filaments to buckle. This buckling force is different depending on the stiffness of the filament. So, doctors will be able to use these different filaments to detect what force the child can feel and what force the child can't feel.

The nerve conduction study, also called a nerve conduction velocity test, is a test used to measure the speed of conduction of an electrical impulse through a nerve to determine the extent of nerve damage. The doctor will place several patches on the child's skin, which are attached to a testing machine. A very mild electric impulse is sent to each nerve the doctor wants to test, and the electrical activity is recorded using the testing machine.

The electromyography test uses a needle electrode that is attached by wires to a recording machine is inserted into a muscle. The electrical activity in that muscle is recorded while the muscle is at rest. Then the doctor will ask the child to tighten or contract the muscle slowly and steadily. The electrical activity is also recorded. The electrode may be moved a number of times to record the activity in different areas of the muscle or in different muscles [2].

Overall, these tests are useful to doctors and clinicians to diagnose nerve damage in children.

### 3.3 Median Nerve

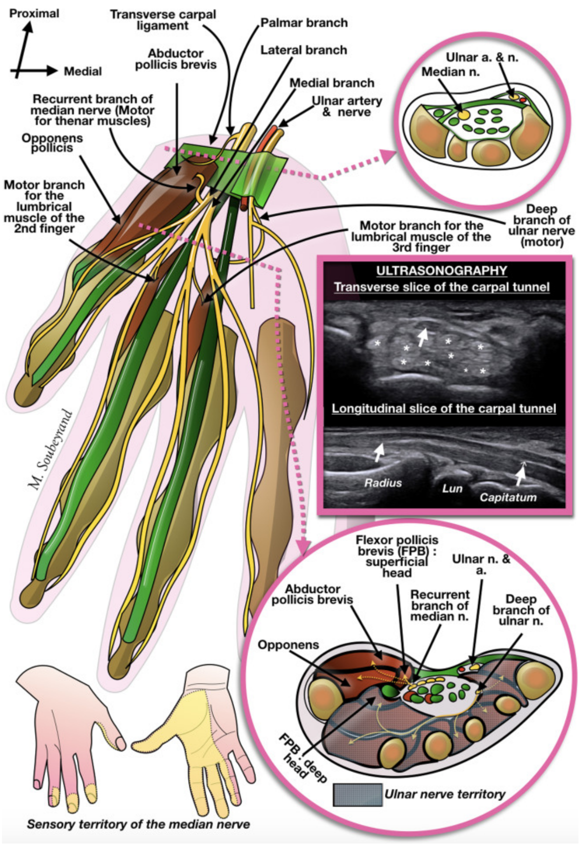


Fig. 7. Median Nerve Schematic

One common nerve that impairs the sensory function of the hand is the median nerve. The median nerve is a mixed sensory nerve that runs from the brachial plexus section of your brain through the carpal tunnel section of your wrist to the your hand. It receives motor commands from the central nervous system and brings back sensory influx from the areas that innervates.

These pathways bring various types of sensory information back to the central nervous system, ”such as epicritic sensation (conscious proprioception, baresthesia, pallesthesia), spinothalamic tract (protopathic sensation: temperature and pain) and spinocerebellar (unconscious proprioception) [6].” To provide some context, these medical terms will be defined.

- **Epicritic Sensation** The sensibility to gentle stimulations permitting fine discriminations of touch and temperature, localized in the skin [7].
- **Proprioception** The sense or perception, usually at a subconscious level, of the movements and position of the body and especially its limbs, independent of vision; this sense is gained primarily from input from sensory nerve terminals in muscles and tendons (muscle spindles) and the fibrous capsule of joints combined with input from the vestibular apparatus [8].
- **Baresthesia** The sensibility for weight or pressure [9].
- **Pallesthesia** The sensibility to vibrations; the peculiar vibrating sensation felt when a vibrating tuning-fork is placed against a subcutaneous bony prominence of the body [10].
- **Spinothalamic Tract** The spinothalamic tract is an ascending pathway of the spinal cord. Together with the medial lemnicus, it is one of the most important sensory pathways of the nervous system. It is responsible for the transmission of pain, temperature, and crude touch to the somatosensory region of the thalamus [11].
- **Protopathic** Denoting a supposedly primitive set or system of peripheral sensory nerve fibers conducting a low order of pain and temperature sensibility that is poorly localized [12].
- **Spinocerebellar** Pertaining to the spinal cord and cerebellum [13].

As one can see, the median nerve is responsible for communicating sensory and muscular information from the brain to the hand. In particular, the median nerve is responsible the flex and the sensation on palmar side of the hand for the first three fingers (index, middle, and ring finger). Additionally, it is also responsible for the flex of the wrist and the grip of the thumb finger on an object [6].

### 3.4 Current Treatments

Once the child is diagnosed with peripheral neuropathy and the severity of the condition is evaluated, therapy, treatment, and management strategies are pursued to improve the child's symptoms and welfare. If the peripheral neuropathy is caused by an underlying disease, it can be improved with the treatment of the underlying condition, such as diabetes or auto immune diseases.

The neuropathic pain experienced by the child due to peripheral neuropathy can be treated through the following methods:

- Over-the-counter or prescription pain relievers
- Anti-seizure or anti-depressant medications
- Topical creams or patches
- Physical therapy
- Occupational therapy
- Desensitization therapy
- Exercise
- Psychological counseling
- Electrode nerve stimulation
- Lifestyle changes (weight loss or activity modifications)
- Massage therapy
- Acupuncture
- Nerve blocks
- Surgery

Although these therapies help children and adults deal with and cope with their symptoms, it is not a solution to replace the nerve functionality lost to peripheral neuropathy. As children and toddlers are learning to use their hands and feet, the sensory information from their feet and hands are critical input to be used as a learning tool to properly control their peripherals. Unfortunately, children with peripheral neuropathy are at a severe disadvantage compared to their peers in early childhood development. There is a clinical need for a device to replace the sensory information lost in the children's hands or feet due to peripheral neuropathy [2].

### 3.5 Wearable Sensor Glove

Fig. 8. Commercially Available Sensor Glove [14]

This paper will focus on the development of a wearable sensor glove as humans need more sensory information from their hand to properly control the movement and actions of their hands as compared to their feet. Glove-based sensor systems are one of the most significant devices that assess quantities related to hand movements. Many different fields are interested in integrating wearable sensor glove technology into their research. Some of these fields are neuroscience, biomedical engineering, robotics, human-machine interfaces, human-computer interaction, and artificial intelligence. Researchers in the fields of medical rehabilitation and physiological assessments are especially interested in using wearable sensing systems, as wearable sensing systems will have a high impact on their research. The sense of touch allows humans to perform coordinated and efficient interactions with their environment and perform a huge number of tasks in everyday life.

Glove-based systems for medical applications are primarily focused on the acquisition of multiple types of data, including pinching and gripping force, temperature, motion ranges of hand joints, pressure, etc... A wearable sensor glove is the optimal wearable device as it allows for reduced invasiveness, increases the accuracy and repeatability, and it improves the complexity of the measurements used to simultaneous measure different sensors [15].

Overall, there is a clinical need for a wearable device to replace the sensory information that is lost in the children's hands or feet due to peripheral neuropathy. The purpose of the wearable glove proposed in this paper is to sense the physical interaction between the subject's hand and its surroundings. Specifically, the wearable sensor glove will be designed to measure the pressure on the child's fingertips, the contact temperature of their fingertips, and the flex and grip of the child's fingers.

## 4 Current Market Solutions

Based on the available technologies in the market, there is not a wearable glove that combines all three sensor nodes into one form factor. A wearable glove that can detect pressure, finger flex, and temperature is required for patient to properly sense the environment around them. A pressure sensor allows a subject to detect forces placed on their fingertips. This will enable a child to detect sharp objects, learn when a large force is exerted on their fingers, and have pressure feedback to properly grip and control objects and perform everyday tasks. A temperature sensor allows a child to prevent themselves from burning their hand when touching hot objects. A strain sensor allows the child to learn how much to flex their fingers to grip objects and to learn how to secure objects in their hand and prevent them from slipping out of their hand. All three sensor modes are necessary to truly enhance the sensory input from the hand of the child. To properly analyze how the current available solutions do not meet the needs of clinicians today, the requirements for each sensor node is described.

## 4.1 Functional Requirements

As described in the introduction, functional requirements, {FR}, and design parameters, {DP}, are used to evaluate a solution in the product definition phase of the design process. The customer attributes, {CA}, are translated into functional requirements, {FR}. These values for each sensor node are listed below.

### 4.1.1 Pressure Sensor

The following list contains the customer attributes, {CA}, that describe the customer requirements for a pressure sensor in a wearable sensor glove.

- $CA_1$ Low power consumption sensing operation
- $CA_2$ Thin sensor to not impede normal hand operation
- $CA_3$ Large enough pressure sensor to cover the area of the fingertip
- $CA_4$ Detect small forces
- $CA_5$ Large measurement gradient between small and large forces

These customer attributes, {CA}, are translated into functional requirements, {FR}, as seen below.

- $FR_1$ Sensor measurement consumes less than 0.04 W
- $FR_2$ Sensor thickness less than 1 mm
- $FR_3$ 5 mm x 5 mm area
- $FR_4$ Sensitivity to detect forces as low as 0.04 N
- $FR_5$ .04 Newton per analog unit

### 4.1.2 Strain Sensor

The following list contains the customer attributes, {CA}, that describe the customer requirements for a strain sensor in a wearable sensor glove.

- $CA_1$ Length to cover mid-finger knuckle
- $CA_2$ Stretchable and flexible material
- $CA_3$ Thin sensor to not impede normal hand operation
- $CA_4$ Low weight to not affect the hand's inertia
- $CA_5$ Low power consumption sensing operation

These customer attributes, {CA}, are translated into functional requirements, {FR}, as seen below.

- $FR_1$ Length of sensor between 25 mm and 50 mm
- $FR_2$ Sensor can bend 90 degrees around at a 10 mm radius
- $FR_3$ Thickness less than 1 mm
- $FR_4$ Weight less than 0.25 g
- $FR_5$ Sensor measurement consumes less than 0.08 W

### 4.1.3 Temperature Sensor

The following list contains the customer attributes, {CA}, that describe the customer requirements for a temperature sensor in a wearable sensor glove.

- $CA_1$ Wide temperature range
- $CA_2$ Thin sensor to not impede normal hand operation
- $CA_3$ Flexible sensor material
- $CA_4$ Sensitive enough to detect small temperature changes
- $CA_5$ Low power consumption sensing operation

These customer attributes, {CA}, are translated into functional requirements, {FR}, as seen below.

- $FR_1$ 0 C to 100 C temperature range
- $FR_2$ Thickness less than 1 mm
- $FR_3$ Bend radius of 25 mm
- $FR_4$ Sensitivity to detect 0.10 C per analog unit

- $FR_5$ Sensor measurement consumes less than 0.04 W

## 4.2 Current Solutions

Commercially available wearable sensor gloves are designed to meet a set objective, and the sensors that are implemented into the glove vary in order to achieve that set goal. Unfortunately, there is a not a glove on the market that combines pressure, strain, and temperature into a single glove. So, each product presented below only achieves one out of the three sensor nodes. Therefore, the sensor technology used in these commercial wearable sensor gloves is analyzed. Then, each commercial product is evaluated using the first design axiom, Independence Axiom, to determine if the design parameters meet the functional requirements.

### 4.2.1 Wearable Glove: Pressure Sensor


Fig. 9. TactileGlove - Hand Pressure Measurement [16]

Fig. 9 shows a commercially available pressure sensor glove. This product exhibits the following characteristics: 0.1 oz or 3g force detection, wireless data communication through BLE, 65 individual sensing elements within the glove, full scale range of 88 psi, a maximum force of 70N being applied to the thumb and finger tips, a minimum sensitivity of 0.04 N, and a thickness of 2.6 mm [16].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ On-board capacitance-based sensor, 0.02 W
- $DP_2$ Sensor thickness of 2.6 mm (not including glove material)
- $DP_3$ Sensor size is 5 x 5 mm in area
- $DP_4$ Force range of 0.03 N - 70 N
- $DP_5$ 0.04 N per analog unit

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 1. Independence Axiom Application: Pressure

| $FR_\#$ | [A] | | | | | $DP_\#$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | 0 | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

### 4.2.2 Wearable Glove: Strain Sensor

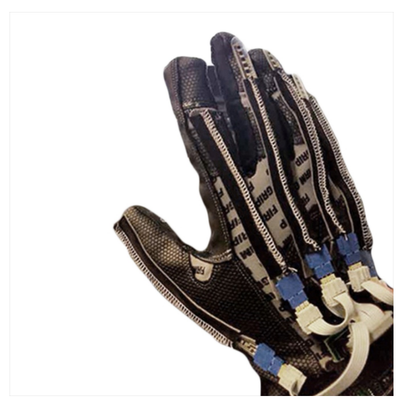

Fig. 10. Flexpoint - USB Glove Kit [17]

Fig. 10 shows a commercially available strain sensor glove. This product is designed to measure and record the flex in the fingers through the use of strain gauges in the fingers. As the finger is flexed, the resistance in the strain gauge changes. This data is transmitted through a USB cable to a computer that is recording data. This product exhibits the following characteristics: USB tethered data connection, 3 longer bend sensors for the index, middle, and ring fingers, 2 shorter bend sensors for the thumb and pinky, the glove is washable, and the sensors and electronics are not waterproof [17].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ Length of 77 mm
- $DP_2$ Bend radius of 120 mm
- $DP_3$ Thickness of 0.45 mm
- $DP_4$ Weight of 0.27 g
- $DP_5$ Resistance based measurement, 0.07 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 2. Independence Axiom Application: Strain

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | 0 | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | 0 | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | 0 | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

#### 4.2.3 Wearable Glove: Temperature Sensor


Fig. 11. Holik SensPro - Protective Temperature Glove [18]

Fig. 11 shows a commercially available temperature sensor glove. This product exhibits the following characteristics: all-textile protective fabric, surface temperature measurements, measure temperature of remote objects using infrared temperature measurement, on-glove bar graph, status led, BLE connectivity, power and mode switch, and on-glove data collection module [18].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ -50 C to 500 C temperature range
- $DP_2$ Thickness of 0.5 mm
- $DP_3$ Bend radius of 15 mm
- $DP_4$ 25 C per analog unit
- $DP_5$ Resistance based measurement, 0.07 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 3. Independence Axiom Application: Temperature

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | 0 | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | 0 | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

## 5 Alternative Solutions

As the current commercial product does not meet the needs for a clinical application, alternative solutions are proposed below. These alternative solutions will be evaluated using the principals of the axiomatic design theory for each sensor node: pressure, strain, and temperature.

### 5.1 Pressure Sensor

#### 5.1.1 Solution I

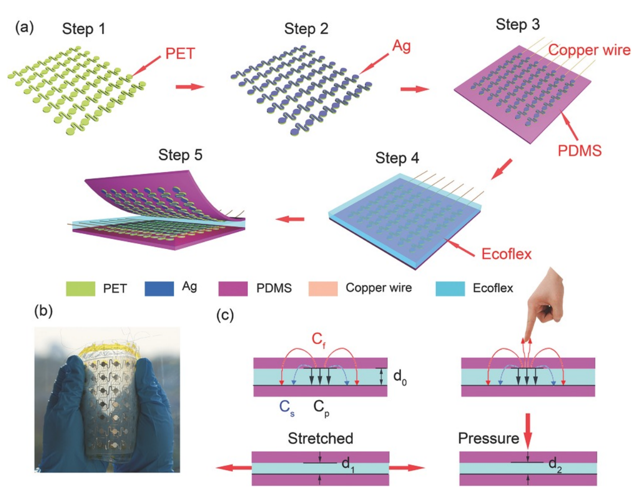


Fig. 12. PDMS Based Pressure Sensor [19]

Fig. 12 shows a pressure sensor design made at The Beijing Institute of Nanoenergy and Nanosystems. This design exhibits the following characteristics: a detection limit of 6 Pa or 0.5 mg of force, stretching up to 70% of its size, flexible material construction, a sensitivity of 0.12 (ratio of the capacitance change to base capacitance) and a fast response time of 100 ms [19].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ Capacitance-based measurement, 0.04 W
- $DP_2$ Thickness of 0.2 mm
- $DP_3$ Sensor area of 5 mm x 5 mm
- $DP_4$ Minimum force detection of 0.02 N
- $DP_5$ 0.12 $\frac{\Delta C}{C}$

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 4. Independence Axiom Application: Pressure

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is an uncoupled design. Therefore, the design does not violates the Independence Axiom and it is an eligible candidate as an alternative solution.

### 5.1.2 Solution II

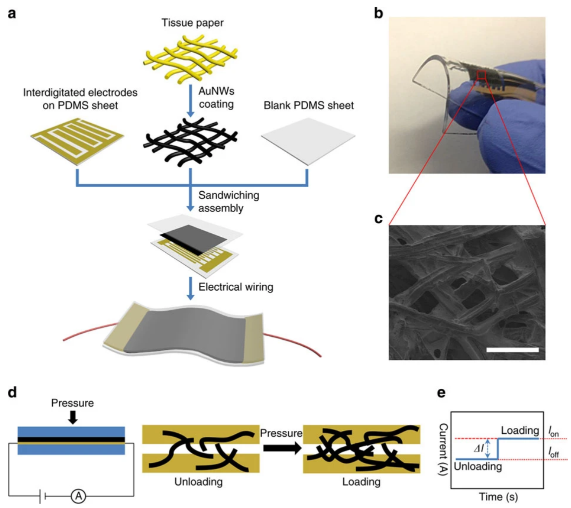


Fig. 13. Gold Nanowire Pressure Sensor [20]

Fig. 13 shows a pressure sensor design made at Monash University in Victoria, Australia. This design exhibits the following characteristics: flexible substrate, ultrathin gold nanowire-impregnated tissue paper between two thin polydimethylsiloxane sheets, low energy consumption less than 30 microwatts, detects force as low as 13 Pa, response time less than 17 ms, high sensitivity greater than 1.14 $kPa^-1$, sensing area of 8 x 8 $mm^2$, and can be operated under a battery voltage of 1.5 V [20].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ Capacitance-based measurement, 30 $\mu$W
- $DP_2$ Thickness of 0.5 mm
- $DP_3$ Sensor area of 8 mm x 8 mm
- $DP_4$ Minimum Force Measurement 13 Pa
- $DP_5$ Sensitivity greater than 1.14 $kPa^{-1}$.

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 5. Independence Axiom Application: Pressure

| $FR_\#$ | [A] | | | | | $DP_\#$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | 0 | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

### 5.1.3 Solution III

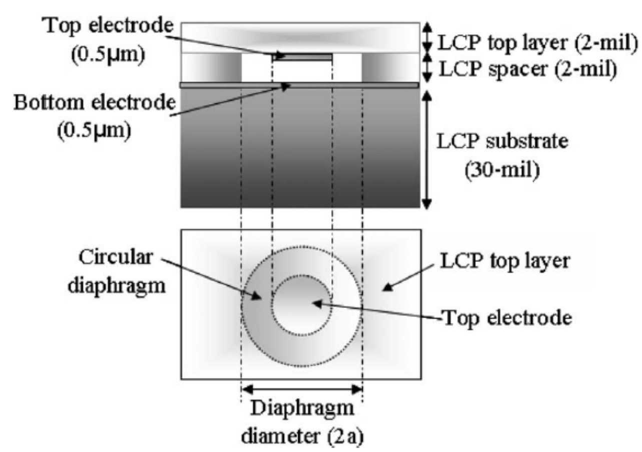


Fig. 14. Liquid Crystal Polymer Pressure Sensor [21]

Fig. 14 shows a pressure sensor design made at Auburn University in Auburn, Alabama. This design exhibits the following characteristics: rigid substrate, novel liquid-crystal polymer, easily printed using printed-circuit-processing techniques, diaphragm diameter of 3.2 mm and a maximum capacitance change of 0.277 pF for an applied pressure in the range of 0-100 kPa [21].

Next, the design parameters, {DP}, are described to detail how they would satisfy the functional requirements, {FR}.

- $DP_1$ Capacitance-based measurement, 0.03 mW
- $DP_2$ Thickness of 0.86 mm
- $DP_3$ 3.2 mm x 3.2 mm sensor area

- $DP_4$ Minimum detectable force of 0.03 N
- $DP_5$ 0.277 pF for every 100 kPa (1.39 mV/kPa)

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 6. Independence Axiom Application: Pressure

| $FR_\#$ | [A] | | | | | $DP_\#$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | 0 | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | 0 | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

## 5.2 Strain Sensor

### 5.2.1 Solution I

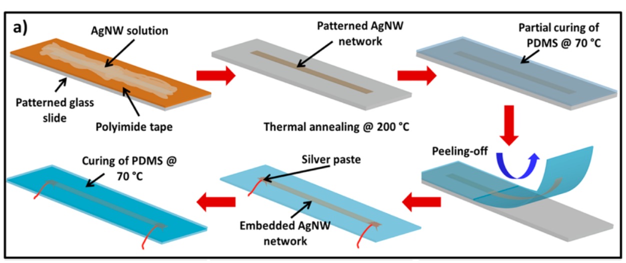


Fig. 15. Silver Nanowires Strain Sensor [22]

Fig. 15 shows a strain sensor design made at The Korea Advanced Institute of Science and Technology in Daejeon, South Korea. This design exhibits the following characteristics: highly stretchable and sensitive strain sensors, nanocomposite of a silver nanowire network, tunable gauge factors in the ranges of 2 to 14, high stretchability up to 70%, high linearity and sensitivity [22].

- $DP_1$ Length is 50 mm
- $DP_2$ Bending radius of 6 mm
- $DP_3$ Thickness of 0.5 mm
- $DP_4$ Weight less than 0.2 g
- $DP_5$ Resistance-based measurement, 0.03 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 7. Independence Axiom Application: Strain

| $FR_\#$ | [A] | | | | | $DP_\#$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is an uncoupled design. Therefore, the design does not violates the Independence Axiom and it is an eligible candidate as an alternative solution.

### 5.2.2 Solution II

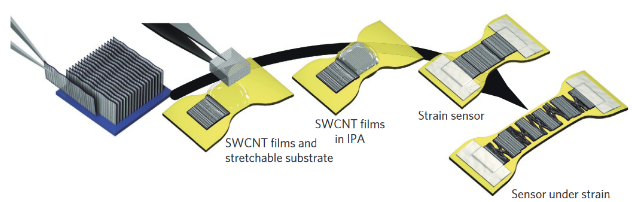


Fig. 16. Carbon Nanotubes Strain Sensor [23]

Fig. 16 shows a strain sensor design made at National Institute of Advanced Industrial Science and Technology in Tsukuba, Japan. This design exhibits the following characteristics: stretchable carbon nanotubes, strain sensors capable of measuring strains up to 280%, high durability, fast response, 35% relative resistance change, and low creep [23].

- $DP_1$ Length of the sensor is 50 mm

- $DP_2$ Bend radius of 8 mm
- $DP_3$ Thickness of 0.5 mm
- $DP_4$ Weight less than 0.2 g
- $DP_5$ Resistance-based measurement, 0.03 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 8. Independence Axiom Application: Strain

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is an uncoupled design. Therefore, the design does not violates the Independence Axiom and it is an eligible candidate as an alternative solution.

### 5.2.3 Solution III

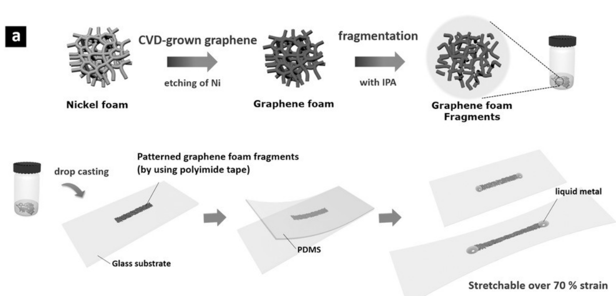


Fig. 17. Graphene Foam Fragments Strain Sensor [24]

Fig. 17 shows a strain sensor design made at Korea University in Seoul, South Korea. This design exhibits the following characteristics: graphene foam fragments, percolation network of the graphene foam fragments, high sensitivity with a GF of 15 to 29, high stretchability up to 70%, and high durability with up to 10,000 stretching-releasing cycles [24].

- $DP_1$ Length of the sensor is 20 mm
- $DP_2$ 90 degree at a bend radius of 10 mm
- $DP_3$ Thickness of 0.55 mm
- $DP_4$ Weight less than 0.2 g
- $DP_5$ Resistance-based measurement, 0.03 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 9. Independence Axiom Application: Strain

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | 0 | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | 0 | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

### 5.3 Temperature Sensor

#### 5.3.1 Solution I

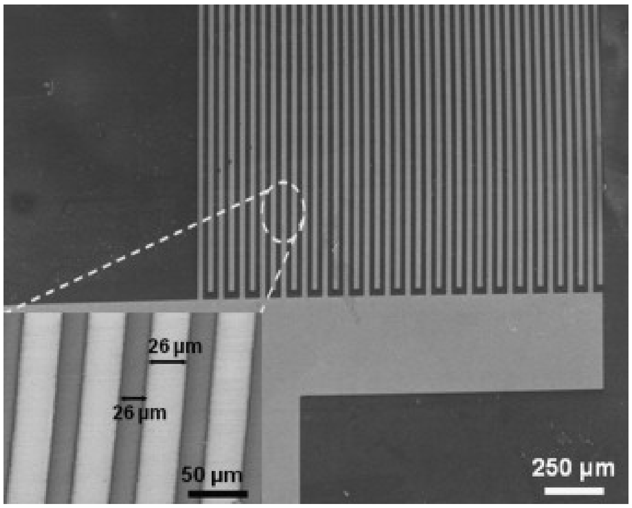


Fig. 18. Cellulose Temperature Sensor [25]

Fig. 18 shows a strain sensor design made at Inha University in Incheon, South Korea. This design exhibits the following characteristics: nanoscaled polypyrrole via in situ polymerization, capacitance of flexible sensor increased linearly with increasing temperature, [25].

- $DP_1$ 15 C to 50 C temperature range
- $DP_2$ Thickness of 0.2 mm
- $DP_3$ Bend radius of 2 mm
- $DP_4$ 0.2 pF/C
- $DP_5$ Capacitance-based measurement, 0.01 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 10. Independence Axiom Application: Temperature

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | 0 | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

#### 5.3.2 Solution II

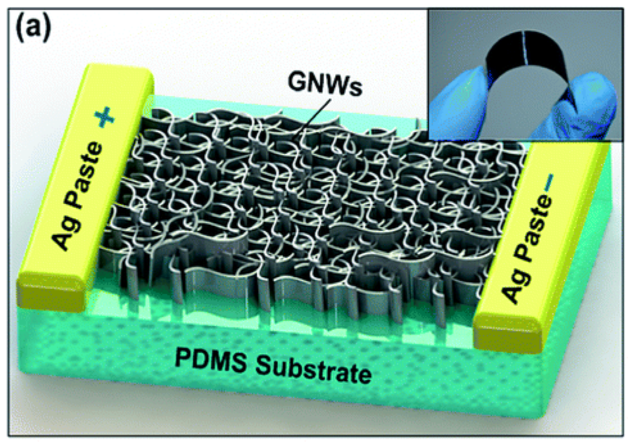


Fig. 19. Graphene Nanowalls Temperature Sensor [26]

Fig. 19 shows a strain sensor design made at the Chinese Academy of Sciences. This design exhibits the following characteristics: made from graphene nanowalls and PDMS, positive temperature coefficient of resistivity as high as 0.214 $\frac{1}{C}$, and a wide operating temperature (20 to 120 C) [26].

- $DP_1$ 20 C to 120 C temperature range
- $DP_2$ Thickness of 0.5 mm
- $DP_3$ Bend radius of 50 mm
- $DP_4$ 0.20 C per analog unit
- $DP_5$ Resistance-based measurement, 0.03 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 11. Independence Axiom Application: Temperature

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | 0 | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | 0 | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | 0 | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is not an uncoupled design or a decoupled design. Therefore, the design violates the Independence Axiom.

### 5.3.3 Solution III

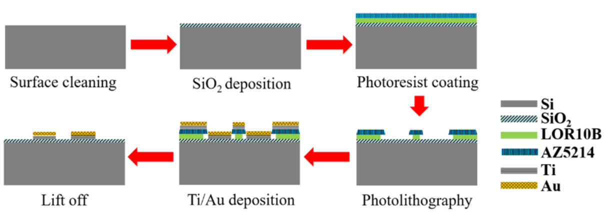


Fig. 20. Gold Film Temperature Sensor [27]

Fig. 20 shows a strain sensor design made at the Huazhong University of Science and Technology in Wuhan, China. This design exhibits the following characteristics: gold film resistive-based temperature sensor, gold material has great resistance to oxidation and it is compatible with micro-fabrication processes, temperature measurement accuracy to be 0.08 C, and the repeatability within seven days was 0.03 C [27].

- $DP_1$ -50 C to 200 C temperature range
- $DP_2$ Thickness of 0.01 mm
- $DP_3$ Bend radius of 15 mm
- $DP_4$ 0.08 C per analog unit
- $DP_5$ Resistance-based measurement, 0.03 W

Then, the design matrix, [A], can be calculated using Eq. 1 and the design matrix, [A], can be evaluated to determine if it satisfies the Independence Axiom.

Table 12. Independence Axiom Application: Temperature

| $FR_{\#}$ | [A] | | | | | $DP_{\#}$ |
|---|---|---|---|---|---|---|
| $FR_1$ | X | 0 | 0 | 0 | 0 | $DP_1$ |
| $FR_2$ | 0 | X | 0 | 0 | 0 | $DP_2$ |
| $FR_3$ | 0 | 0 | X | 0 | 0 | $DP_3$ |
| $FR_4$ | 0 | 0 | 0 | X | 0 | $DP_4$ |
| $FR_5$ | 0 | 0 | 0 | 0 | X | $DP_5$ |

As one can see, the design matrix, [A], is an uncoupled design. Therefore, the design does not violates the Independence Axiom and it is an eligible candidate as an alternative solution.

## 5.4 Application of the Information Axiom

The Independence Axiom was applied to the alternative solutions proposed for each sensor node. For the pressure sensor node, the only alternative solution that satisfied the Independence Axiom was Solution I: PDMS Based Pressure Sensor. The design parameters that comprised Solution I satisfied all of the functional requirements set forth by the customer attributes. Therefore Solution I: PDMS Based Pressure Sensor will be used to construct a wearable sensor glove for this clinical application.

For the strain sensor node, there were two alternative solutions that satisfied the Independence Axiom: Solution I: Silver Nanowires Strain Sensor, and Solution II: Carbon Nanotubes Strain Sensor. In order to select the optimal design, the second design axiom, Information Axiom, can be used. The Information Axiom states that the design with the least information content is the optimal design. That is determined by using a probability based metric to determine which design is most likely to meet the design parameters set forth by the functional requirements. Using the theory stated in the 'Background Information' section of this report, Tab. 13 is generated to provide an overview of the parameters used to define the system range and the common range for each design.

Table 13. Information Axiom Range: Strain

| $Solution_{\#}$ | $FR_1$ [mm] | $FR_2$ [mm] | $FR_3$ [mm] | $FR_4$ [g] | $FR_5$ [W] | $FR_6$ [%] | $FR_7$ [GF] |
|---|---|---|---|---|---|---|---|
| $System$ | 25-50 | 2-10 | 0-1 | 0-0.25 | 0-0.08 | 50-100 | 5-20 |
| $Solution_1$ | 20-100 | 5-50 | 0.4-0.6 | 0.1-0.3 | 0.03-0.05 | 0-70 | 2-14 |
| $Solution_2$ | 20-100 | 8-50 | 0.4-0.6 | 0.1-0.3 | 0.03-0.05 | 0-280 | 0.06-0.82 |

Table 14. Information Axiom Application: Strain

| $Solution_{\#}$ | $FR_1$ | $FR_2$ | $FR_3$ | $FR_4$ | $FR_5$ | $FR_6$ | $FR_7$ | $FR_{SUM}$ |
|---|---|---|---|---|---|---|---|---|
| $Solution_1$ | 1.42 | 3.17 | 0 | 0.415 | 0 | 0 | 0 | 5.01 |
| $Solution_2$ | 1.42 | 3.07 | 0 | 0.415 | 0 | 0 | $\infty$ | $\infty$ |

Two additional functional requirements are added to distinguish between the two alternative solutions. The functional requirements are listed below.

- $FR_6$ High stretchability at least 50%
- $FR_7$ Gauge Factor of at least 5

The information content for each category is calculated using Eq. 3 and the minimum information content for the design is calculated using Eq. 4. The results of this analysis can be seen in Tab. 14. By performing this analysis, it can be see that the uncoupled design matrix given for Solution I: Silver Nanowires Strain Sensor has the minimum information content, whereas Solution II: Carbon Nanotubes Strain Sensor as an infinite amount of information as one design parameter, $DP_7$, does not meet the functional requirement, $FR_7$. Therefore, we can concluded that Solution I: Silver Nanowires Strain Sensor is the optimal solution and it will be used to construct a wearable sensor glove for this clinical application.

For the temperature sensor node, the only alternative solution that satisfied the Independence Axiom was Solution III: Gold Film Temperature Sensor. The design parameters that comprised Solution I satisfied all of the functional requirements set forth by the customer attributes. Therefore Solution III: Gold Film Temperature Sensor will be used to construct a wearable sensor glove for this clinical application.

## 6 Conclusions

The work presented in this paper is intended to demonstrate that the selection of the technology used in a sensor can be easier to understand and easier to implement if the design process was approached in a systematic fashion. The two design axioms, Independence Axiom and Information Axiom, provide a formal structured methodology to evaluate whether the design parameters satisfy the functional requirements. This methodology guides the synthesis of designs by forcing marketers, business managers, and entrepreneurs to work with customers to explicitly define the customer attributes. Once these are explicitly defined, engineers will work with these groups to translate those attributes into functional requirements. During the product design stage of development, engineers propose a solution to the presented problem and detail the design parameters that compose the design. In order to validate that the design parameters meet the functional requirements, the Independence Axiom and the Information Axiom are used. Through the use of these scientific methods, the optimal solution is selected and progressed to the next stage of development.

By applying this theory to the development of a wearable sensor glove, it shows that the optimal solution for the three different sensor nodes, pressure, strain and temperature, are the following: PDMS Based Pressure Sensor, Silver Nanowires Strain Sensor, and Gold Film Temperature Sensor. Overall, the generalized design axioms are broad in scope and they can be applied to most design problems in any field.

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