Nanotechnology and Nanosensors
by Prof. Hossam Haick

Final Project
The Nano-Detector

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Abstract

Nano-detector, is composed of nanometric detectors which mimics the biological nose of dogs and human in its function. This system is designed in aim to detect the specific and special volatile organic compounds which are emitted through the skin of humans using a special highly sensitive, accurate, and specific nanosensors made from unique compounds in a nanometric scale: CNTs, SiO2/Si, and Si NWs. This approach can be implemented in cost effective applications that can promote and contribute to humanity and help in reducing the number of victims and fatalities worldwide when its primary application is tracking survivors under rubble, but it can be implemented in further applications such as, finding kidnapped and lost people, searching for suspects in crime scene, and diagnosing diseases.

Introduction

Earthquakes, tornados, floods, and wars… all these terms have one significant thing in common, they are all disasters, which all cause a high number of victims and a remarkable death toll amongst humankind! One of the most prominent reasons for death from these disasters is due to the collapse of buildings and thus entrapping people under the very deep wreckage, where most people are buried alive due to the difficulty of finding and locating them. Today, tracking survivors is done by training dogs which are utilized due to their strong sense of smell to track the survivors, however this usage has too many limitations [1]: Starting with the fact the dogs are living organisms and cannot work for a continues and long period of time, furthermore these trained dogs are expensive and aren’t reachable for all communities especially in the third world countries! But what if we could mimic this super ability that dogs have to implement it in a nanosensor which will be able to replace dogs!? 

Nano-detector, is a highly sensitive, cost-effective, accurate, reliable sensor with nanometric diameters which is able to mimic the smelling sense. This nanosensor is based on the olfactory receptors mechanism in the biological nose, which is composed of unspecific receptors that detect various volatile compounds and the interaction of all the receptors together induce a nerve impulse that is recognized as a smell by the brain [2].
Our Nano-detector is specified to detect special volatile organic compounds (VOCs) which are excreted from humans' skin [1,3]. And similar to the nose, our system will be unspecific in this spectrum of molecules, it will be able to detect VOCs with various composition, since every human being is different in terms of the composition of molecules that are emitted from their body. Thus, it will be applied to declare whether there are live humans in a specific region or not.

The system can be applied in various ways, it can be connected to a bracelet that the rescuers wear as they search for survivors, or alternatively it can be connected with the dog’s collar which will remarkably enhance their search process and save time.

In conclusion, the approach may be developed to have further applications that will all highly lead to a better, meaningful and prosperous future for the humanity.

Literature review

(a) Multidisciplinary presentation and discussion of the overall design approach

Technologies and approaches to detect human odor have drawn a wide interest due to the fact that they have a high potential and importance to diverse fields that can benefit humanity, such as: criminology, security screening and investigation, tracking and looking for missing people and survivors under the rubble, and diagnosing diseases.

This approach can be applied due to the fact that humans' body have a distinctive odors that can be considered as a unique signature to identify them, these odors are called volatile organic compounds (VOCs), which are chemical compounds that are emitted from the secretions (mainly the sweat) of the human's skin[1]. The current approaches to detect these odors include technological systems, such as: GC combined with a detector (GC/MS, GC/gas detector,GC/mini-PDII) [4-7], fluorescent image sensors [8], and the conventional way: using trained canines [1]. All these approaches have various disadvantages, the current technologies don't detect and measure the compounds in a "real time", consuming time, have a low sensitivity and aren't continues since there is a need to first sample and collect the compounds and then to analyze them to gain the results. For the trained dogs, they also have limited abilities too, such as: Limited working periods, their cost is relatively high, and their number worldwide is limited. However, today the nano-technology field comes up
with solutions that can overcome these limitations, and thus the approach that we
designed is called the Nano-detector.

The Nano-detector is based on the "electronic nose" applications which are sensors
that mimics the biological and mammalian olfaction mechanism of humans and dogs
(as well as of other animals), they are composed of an array of non-specific multiple
cross-reactive sensors (fig.1) [9] which adopt the biological nose concept of
“smelling”, it’s considered so useful and applicable due to the wide range of
advantages that it provides: High sensitivity, selectivity and specificity, reliable, cost
effective, fast performance, small characteristic range of size (1 -1 100nm), large
surface to volume ratio, and the ability to cap the nanoparticles with a hybrid
combination of physical and chemical functions.

![Cross-Reactive Sensing](image)

Figure 1: A cross reactive sensing approach.

**Project description**

**(b) Fabrication**

The basic idea of this approach is to mimic the smelling mechanism in the biological
system, since the process of smelling in the nose happens due to the various olfactory
receptors that detect a wide range of volatile compounds; Each receptor is not specific
to one kind of molecules as it has affinity to various voltaic molecules, and every
single molecule can bind to several receptors but with different affinities [2]. When
the molecules bind to a receptor, its structure changes and the overall change of
structure for each receptor causes a cascade of signals that are transmitted by nerves
to the brain and there the smell is analyzed and recognized [2].

The system that we designed is based on this process in a nanometric scale. The Nano-detector is composed of two major parts: A system that detects VOCs
which is the array of sensors (mimics the olfactory receptors), and a software system which is the principle component analysis (PCA) and the screen (mimics the brain), the general concept of the system process principle in described in figure 2.

Figure 2: General overview of the Nano-detector operation principle

Although the overall system will mimic the principle of the smelling sense, it will be different in some aspects due to the target and the specific application that it's designed to accomplish: The system is designed to be capable of differentiating and detecting VOCs emitted from the human's skin, when it will function like the sense of smell just in this broad range of molecules.

Fabrication of the sensor device:

The sensor array is a chemiresistor that combines inorganic nanomaterials with nanometric organic nanoparticles that contribute to chemical sensitivity and selectivity. The core of the device is a chip that is built from special elements, the first layer is a Si film, the second layer above is built from SO2 and contains the array of sensors that will detect the volatiles, and in both sides of the layer there is Au source-drain (Ids) electrodes.

The array of sensors:

The array (fig.3) is a hybrid carbon nanotubes/nanowire sensor array (CNT/Si NWs), when the first kind of sensors are carbon nanotubes sensors (CNT): This kind of sensors have remarkable properties such as, high thermal and electrical conductivity [10]. We chose a random networks of carbon nanotubes (RN-CNTs) that are modified with metal nanoparticles in order to make them capable to have a chemical selectivity, furthermore the RN-CNTs are partially covered with HBC-C12 cap layer that will
enable the sensors to have a high discriminative abilities between different kinds of compounds [9,10] thus giving them further selectivity, sensitivity and even specificity as they will gain the ability to distinguish between different kinds of volatile compounds!

These sensors will be combined with silicon nanowires (Si NWs) coated with a hydrophobic hexyltrichlorosilane (HST) to enable the Si NWs to be sensitive to VOCs [9] and thus causing to our synthesized array to gain an extra sensitivity to VOCs.

Figure 3: The array of sensors

**Principle component analysis (PCA):**

This method is the "brain" of our device, it contains a software that will acquire the data, analyze the signals, recognize and translate them to meaningful result which will be presented on a screen. Since the major aim of the approach is to detect the existence of special kind of VOCs, the screen would show a message (a notification) as the nanosensors detect these VOCs.

(c) **Characterization:**

In order to validate the sensing results there is a need to characterize one or a combination of multiple parameters such as sensitivity, detection limit and dynamic range.

The sensor's characteristics should be determined for the most important target
compounds and the response to the key background compounds, such as water vapor, in real confounding atmospheres.

**Sensitivity:**

Sensitivity indicates the extent of change in a sensor's output when the measured quantity varies. Sensors that measure very small changes must have very high sensitivities. Nanomaterials increase a sensor’s active surface area and generate novel interfaces, thus improving sensitivity and thus increases the degree of component identification, enabling an analysis of individual biomarkers in complex multi-component media. Pattern recognition algorithms, such as principal component analysis (PCA), can then be applied on the entire set of signals to acquire information on the identity, properties and chemical composition of the vapor exposed to the sensors array.

**The limit of detection and quantitation:**

The limit of quantitation is the minimum concentration which can be quantified at a specified level of accuracy and precision.

It may be equal or greater than the limit of detection (fig.4) which is the minimum value or the lowest quantity of a substance that can be distinguished from the absence of that substance within a stated confidence limit [11].

![Image](image.png)

*Figure 4: General definitions of limit of detection and limit of quantitation.*

The limit of detection and quantitation can be seen according to the voltage applied and to the material that the sensor is made from.
(d) Applications:

1. **Searching for people:**
   This is the major application of our Nano-detector, actually this idea was the one that inspired us to think about the whole system in our project! As written above, human body releases VOCs, so "sensing" these VOCs will help us in finding people in many situations, such as: Survivors under the rubble, after any disaster, and then we can aid and help them early and be sure that there is no other people under this rubble.

![Figure 5: Searching for people under the rubble after an earthquake](image)

2. **Medicine:**
   Defect in any metabolic process in our body will change the concentration of VOCs released from the body [1], for example, diabetics emit higher amounts of acetone [12]. So by monitoring and identifying the difference of VOCs concentration, we can discover diseases and identify them early.

![Figure 6: Releasing organic compounds while breathing](image)

3. **Investigation and criminology:**
   By tracking and detecting VOCs emitted from specific person we can find kidnapped and lost people, or even search for suspects in crime scene. Actually, this is done today by trained police dogs, and our suggested system that mimics the smelling ability of the dog can be applied for this aim.

![Figure 7: Tracking a lost person](image)
Conclusions and recommendations:

- The system (Nano-detector) that we designed is based on an array of nanosensors that is composed from combination of two kind of nanodetectors: CNT and Si NWs.
- The combination of the nanosensors gives the system sensitivity, specificity to detect special kinds of VOCs emitted from human’s skin.
- This Nano-detector that we built mimics the sense of smell and can be applied mainly in tracking people buried under the rubble.

Recommendations:

We think that our system can be developed by adding and combining more kinds of sensors, thus enhancing the ability of detection and the applications that the system can accomplish. For example, the array of sensors may also include another kind of sensor, such as, the molecular capped metal nanoparticles (MCNP).
References:


