Large scale body sensing for Infectious Disease Control

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1 Sensor networks to solve major problems

In the last decades, computer researchers have come up with several applications for wireless and sensor technology that are strongly focused on military activities, (personal and corporate) productivity-enhancing processes, or entertainment, many of which, we believe, are less urgent than other global problems like Uncontrolled Population Growth, Non-sustainable use of natural resources, Natural Disaster Relief, and Infectious Disease Control. Hence, we claim that these other problems should become the agenda of future research and development in this area.

In this sense, we chose one of these problems - Infectious Disease Control - and in the following outline a possible future use of sensor networks for monitoring and controlling infectious diseases in large animal (and maybe also human) populations. Because of the several intricate ethical issues involved in monitoring humans, we prefer to explain our application in terms of non-human populations.

The recent news about the Avian influenza disease have shown how fast a mutant and lethal virus disease can spread around our globe, putting in danger large populations of humans.

On the other hand, the relatively large inoculation time of the virus makes it difficult to detect infected animals at an early stage. Therefore, large amounts of animal must be pro-actively sacrificed at any suspicion of an infection.

The other problem is of scale. Since our society is raising animals (cattle, pork, chicken) in such a large scale in an industrial setting (with insufficient space and feeding them badly) we have become unable to monitor each animal's health, and avoid the spreading of diseases at early stages.

Hence, in our point of view it would be very important to develop sensors and an infra-structure that could continuously monitor the health conditions of large-scale animal populations regardless of their location. And using sophisticated methods for automated diagnosis, one would enable warnings of disease or infection suspects, and allow for early control measures by the farmers or the agricultural authorities.

This problem area is particularly important in Brazil, since a significant part of its economy is based on the export of food and meat. For instance, Brazil is the world's biggest exporter of cattle meat handling US$ 2,5 bilions annually. However, because of the current incidents of aftosa fever in some regions of Brazil in 2005, there will be a lost of about US$ 270 millions.

2 Required Technology

With the miniaturization of chips, soon it will be possible to produce penny-size body sensors with small flash memory and short-range wireless communication capabilities. These sensors could be attached to (or implanted in) specific parts of animal, and would be able to probe physical (e.g. temperature, ECG, blood pressure), chemical (e.g. pH, toxins) and biological (e.g. glucose, protein) properties of the body.

This data would be stored in the on-chip memory, and could be transferred through the wireless interface to *collector nodes* (at base-stations installed at gateways or close to the food or water dispensers) as soon as the animal gets close to such a base-station. These base-stations would have a wireless connection to the farmer's office computer, where all the collected data would be analyzed and visualized by specific software for infectious disease control.

The chip would carry the animal's identification and other data, such as age, gender, etc. Moreover, each time two animals get close to each other, the corresponding chips would also exchange data, in order to register this encounter on each chip. This would help to detect whether there is some possibility of infection among two animals.

The chips would have very low power consumption (e.g. few μWatts), and would be powered by several, complementary energy sources, such as battery, solar energy, motion or thermal energy. Such sensors with integrated low-cost radio interfaces, called Ultra-low Power Radios (ULPR), are already being developed [2]. They use specific propagation in and around a body using specific characteristics of of biological tissue, and are powered by micro-generators [1].

Some future versions of such chips may also be equipped with GPS sensors, allowing to track the exact location of each animal.

3 Scenario

The following scenario illustrates the use of the envisaged technology (let's call it the *Animal Health Monitoring System - AHMS*) in controlling and avoiding the spread of infectious diseases at an early stage:

> Consider a cattle farm with a large number of cows (e.g. 20,000 or more), where the animals are regularly moved among several pastures, and where all of the cows are equipped with the AHMS measuring glucose and toxin levels. Moreover, consider that some of the pastures are at the border to another country, where sanitary control is much more relaxed[1], and where some cows have an infectious disease which can be diagnosed by a sudden, but short period of high body temperature.

By continuous monitoring the toxin levels of all the cows, the farmer may early detect that there is some problem with the food or water given to the cattle. Additionally, with AHMS a farmer would be able to monitor the daily temperatures of his animals, and as soon as some animals in the border pasture get the symptoms of the disease, the farmer would be able to conclude that some of his cows have probably been infected. He would then isolate the infected animals from the others, or if necessary, sacrifice them in order to avoid further spread of the infection.

Even for the case that the health problems of an animal disease show up only when the meat is consumed, the AHMS could be used for tracing the health condition history (and the behavior) of the animal(s) who's meat caused the health problems. In fact, this could also help to identify characteristic

[1]This is the probable cause of the recent aftosa fever in some regions of Brazil.

symptoms of unknown diseases and be used by government agricultural agencies for generating cattle health certifications.

Additionally, by using location technologies the scenario can be even more interesting for disease control. For example:

- If the AHMS chips had GPS sensors, the farmer would even be able to detect where most probably is a hole in the fence that allows his cattle to get into close contact with the cattle of the neighbor farm.
- By tracking which other animal has been in contact with the infected ones some days before or after the suspicious symptoms were detected, the farmer would be able to widen the group of animals to be isolated or sacrificed.

4 Main Technological Challenges

In spite of the many benefits that such application might bring, unfortunately, so far, the required technology is not sufficiently accurate and reliable for such a use. In the following, we point to what we believe are the major technological challenges that have to be overcome.

Improvement of sensors for biological and chemical measurements: It is well known that several diseases can be detected diagnostically only through very specific analysis of blood (or other body substances), through detection of external symptoms, or a combination of both. For the former case, sensors would have to be much more sophisticated and would have to have access to blood veins or body organs, etc. Despite the several significant advances in medicine, we believe that there still are a strong demand of research effort in order to enable the development of cheap sensors for "deep body monitoring".

Detection of externally visible symptoms: As mentioned, many diseases are characterized by a combination (and timely correlation) of internal and external symptoms, and hence cannot be properly identified measuring only physical, biological, or chemical data. For example, the Malignant catarrhal fever has external symptoms such as nasal and ocular discharges, conjunctivitis, drooling, hematuria, necrosis and blunting of buccal papillae, enlargement of lymph nodes, diarrhea, among others [4]. Since it is virtually impossible to instrument an animal with sensors to detect all such kinds of symptoms, it would be necessary to identify such symptoms by other means, such as through video cameras, etc. However, such automated detection of external symptoms at individual animals within a large groups is certainly a complex problem in image recognition.

Development of micro-size and cheap power generators: Despite the current efforts to produce motion and thermal power generators, so far these are still very expensive to be deployable in large scale, and to big and heavy to be attached to or implanted in animal bodies. Here we envision need of strong interdisciplinary research in several areas of health and natural sciences.

Low-power radio transmission: In recent years, several advances in low-power (and low-range) radio transmission have been done. More recently, the wireless technology ZigBee [3] has been announced, but according to specialists it's communication efficiency and power consumption are still inappropriate for simple sensor networks. Hence, not only hardware must improve, but research must also be done in communication protocols for efficient and opportunistic wireless transmissions.

Dealing with sensor outage: Sensors, in general, may fail due to many possible problems, ranging from lack of power supply to physical damage. This is the reason why traditional sensor network research counts on redundant nodes and resources. The problem with body sensors is that, so far, they are not cheep and tiny enough so that an animal could be *instrumented* with many of them. On the other hand, data from each individual animal is necessary for a complete monitoring of a herd of animals. Therefore, body sensors must still become smaller and cheaper (and have a reliable power source) so that they can be used for such application.

Dealing with unreliable wireless communication and unpredictable movements: It is well known that short-range wireless communication is very unreliable, not only because of radio interference, but also because nodes (sensors) may be in constant move. For body sensors, this is even worse, as animals move in unpredictable ways and sometimes gather at some places, creating "natural" obstacles for both peer-to-peer and sensor-to-base-station communication. Therefore, we believe that much R&D must be done for creating efficient, and more robust (multi-hop) communication protocols for sensor networks.

5 Conclusion

In this position paper we presented our vision of a future application of sensor and wireless technology that would be useful for dealing with the acute and important problem of infectious disease control. Similarly, there are also many other important and complex real-world problems, such as environmental protection, natural disaster forecast and relief, etc. which may safe many lives today, and/or guarantee life of future generations, and which should be the focus of current (inter-disciplinary) research and development.

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