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A New Strategy for Dimensional Metrology using Smart Dust Networks

Rodolfo Peña, Nicolas Krommenacker and Patrick Charpentier
Centre de Recherche en Automatique de Nancy (CRAN – UMR 7039), Nancy-University, CNRS, BP239,
54506 Vandoeuvre, France
Email: {first.last}@cran.uhp-nancy.fr

***Abstract* – Today most manufacturing efforts in the industry are directed toward producing objects with forms and dimensions specifics. This situation opens the field of dimensional metrology, where several applications are available, and based on different technologies. This paper introduces a new strategy called SMS – Self-Measurement Systems – for dimensional measurement using the smart dust network concept. With this concept, we can imagine that the products will have in the future self-measurement capabilities based on the localization of the smart particles. In this paper we develop the SMS strategy and demonstrate the feasibility using a simple geometric form: the square.**

***Keywords* – dimensional metrology, smart dust networks, neighborhood techniques**

I. INTRODUCTION

Traditional dimensional metrology systems use physical measurement equipment to quantify the geometrical specification (dimension, position, form and surface) from any given object, and they are based on different technologies (e.g. laser, gauge, camera, electromagnetic radiations …) providing different levels of performance. However, measuring machines are often very expensive, centralized and not flexible. The main idea developed in this paper is to use Wireless Sensor Networks (WSN) and localization techniques in order to measure the dimension of the product.

There is currently a system like the Mobile Spatial Coordinate-Measuring System (MScMS) for dimensional metrology based on WSN. This system has been designed to perform simple and rapid dimensional measurements of large size objects using a constellation of network devices (around the product) and a mobile probe [1]. In this case, each position is obtained by using the time difference of arrival (TDoA), measurement between all nodes and the mobile probe.

The novelty of the SMS strategy is to use a smart dust network integrated to the product and localization techniques to determine the dimension of the product. To do this, the product must be endowed with smart dust particles which consist of tiny sensor nodes, able to wirelessly communicate and with autonomous computing capacity. If commercially available nodes do not yet fit to be embedded in the product, many advances in integrated circuits, wireless communications and micro electro-mechanical systems (MEMS) will lead to important reductions in size, power consumption and cost (see Figure 1).

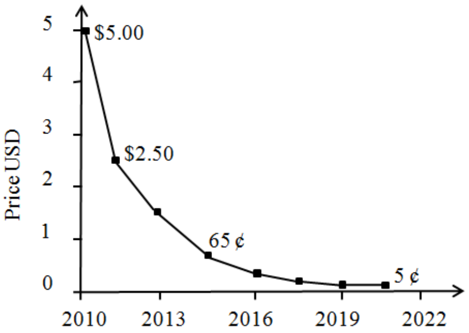


Fig. 1.Price per mote of smart dust: The number of transistors on a chip roughly doubles every two years, resulting in more features, increased performance and cost per transistor.

The main goal of this paper is to develop the Self-Measurement System strategy using smart dust networks. For this we divide this paper as follows. In section II we will give the self-measurement strategy and assumptions needed. Section III presents the basic principles of the SMS strategy: neighborhood density estimation and distance estimation techniques. Finally, the dimension estimation of wooden pieces using the SMS principles is presented.

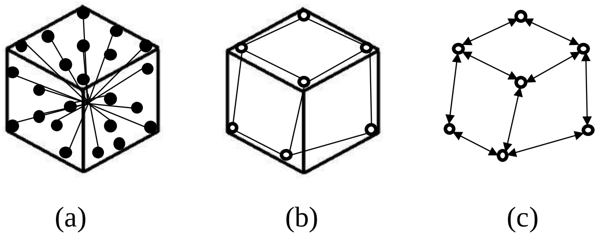


Fig. 2. The Self-Measurement System: (a) smart dust particles are embedded within the system, (b) identification of "border" nodes, and (c) distance estimation between these nodes.

II. THE SMS STRATEGY

The idea of self-measurement strategy is presented in the Figure 2 where we consider a product (here, a cube) with smart particles deployed inside (a). To determine the dimensions of the product, the smart dust network must be able to identify particles which are situated nearest edge intersections (b). Then the distance estimation between these "border" nodes provides dimensional information about the product (c).

To do this, several assumptions must be taken into consideration:

- *The products are endowed with smart dust particles.* This is the main input of the SMS strategy. A large number of small, low-cost and communicating particles (motes) are integrated within the product. According to Moore's Law (see Figure 1), we could consider that this will be feasible in the future.
- *The distribution of motes is uniform in the material conception.* This hypothesis is necessary to ensure that smart dust particles are distributed within all parts of the product, and allow to find its real dimensions.
- *The radio propagation is a spherical model and the transmission range is identical for all motes.* It is dependent of the type of material and its homogeneity. All motes must have the same transmission characteristics whatever their position in the product in order to estimate the neighborhood density.
- *The localization techniques (or ranging) used are accurate and not disturbed by the material of the objects.* In the future the hardware and software capabilities for tiny sensors will have best precision.

Under these conditions the proposed concept confers self-measurement capabilities to the product. This system presents several advantages like the *autonomy* to perform the measurements itself, and the *communication capabilities* in order to communicate their dimensions with other products or other agents in the environment, providing more *flexibility* but low accuracies in comparison with others measurement machines for small-size objects. In any case, the use of WSN presents an advantage in large-size objects [4], where is possible to imagine that the product could recalculate its dimensions after undergoing a transformation during the life cycle.

III. SMS PRINCIPLES

A. *Neighborhood density estimation*

The basic idea of SMS concept is to determinate the border nodes in the smart dust network. In WSN, the neighborhood techniques enable to discover the quantity (q) of nodes in a particular region. This allows identifying the nodes with low quantity of neighbors, i.e. the border nodes.

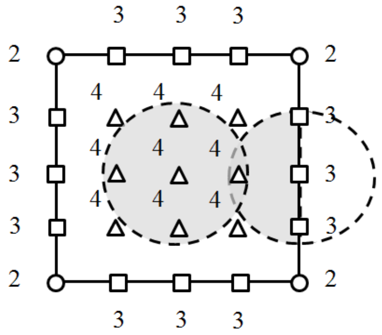
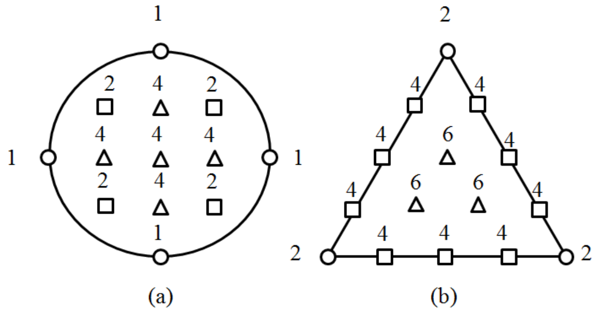


Fig. 3. Neighborhood concept in a square. The border nodes (circles) represent the motes with low quantity of nodes in their neighborhood (gray area)

Figure 3 shows the quantity of neighbors for each node in a grid distribution on a square. The border nodes (circles) represent the motes with low quantity of nodes in their neighborhood (q = 2). The square nodes have 3 nodes, and the triangles 4 nodes in their respective neighborhood with r = 1 (gray area).

This principle is extendible to other geometric figures, with the same assumptions, see Figure 3(a), and 3(b).



(a) (b)

Fig. 4. The applicability of SMS.

However, if the particles are randomly distributed in the product, we must verify that the neighborhood density concept permits to find border nodes [5]. The problem formulated in a square is the following:

> *Considering a square of side A, and a number N of nodes (smart dusts) deployed randomly over the surface* A^2 *(assumptions 1 and 2). Each node has a coverage r which is identical for all (assumption 3). Find a set of nodes M with the minimal neighbor density.*

To do this (principle testing), we developed a simple simulation model agent-based [6], implemented in Netlogo.

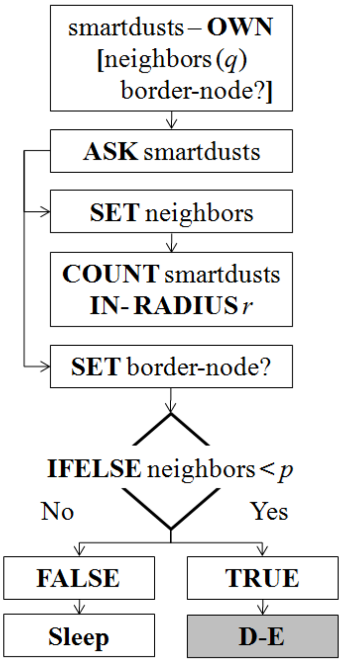


Fig. 5. Abstract agent-based code. D-E represents the distance estimation, the third step in the strategy.

Figure 5 shows an abstract agent-based code where the new parameters are the following:

1) Coverage radius: the transmission range *r* of a smart dust to find others in their neighborhood.
2) Neighbors number : the quantity *q* of motes found in a neighborhood
3) Tolerance: acceptable percentage *p* of the value range s to be a border node.

These simple procedures permit in each mote to determinate if it is a border node (border-node? = **true**). The fixed values are: N = 3000, A = 80, p = {50%, 75%} to provide low and high precision in the dimensional measurement, and r = {10, 20} to test the influence of the coverage in the accuracy.

The result (see Figure 6) shows that the quantity of smart dust borders M (black circles) is variable. For each combination of coverage radius with tolerance percentage there are different levels of M. The mean values of M after 100 simulations for each pair (coverage radius, tolerance percentage) are: (10, 50%) = 9.1123 %, (20, 50%) = 15.2345 %, (10, 75%) = 45.3212%, (20, 75%) = 51.3421%. Therefore, the mean M value is directly proportional to the pair (r, p).

Another result is the relation between the coverage radius r with the value of the side A. The SMS strategy in a square permits to find the border nodes while the value of r is less than $\sqrt{2}$ A. This, because in the value $\sqrt{2}$ A (diagonal) all the smart dusts within the product have the same quantity of neighbors. For this, the best strategy to find border nodes is: with high density, low values in the pair (r, p), and with low density, high values in the pair (r, p), but r always less than $\sqrt{2}$ A ($r < \sqrt{2}$ A).

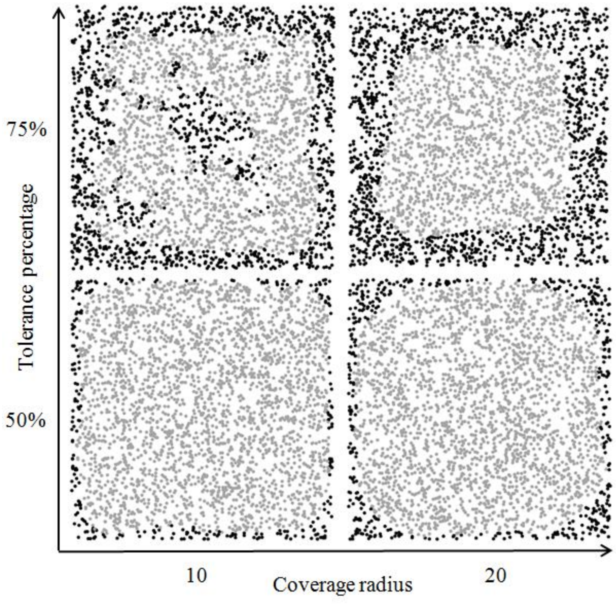


Fig. 6. Simulation results. The percentage of smart dust borders (black circles) is variable, but is directly proportional to the coverage radius, and the tolerance percentage.

B. *Distance estimation*

The previous stage determines the nodes in the product border, i.e. each node is capable to verify itself if it's a border node or not. The next step (final step) consists of distance estimation between "border" particles in order to obtain the dimensions of the product. In this direction, each node must to perform ranging techniques in order to determine their point-to-point distance. Currently, the localization techniques in wireless sensor networks can be divided into two groups: based on distances (range-based), and based on proximity (proximity-based) or free of distances (range-free). We will use the first group, where we need to estimate the distances between nodes, or the angles between them, and there are some like: ToA (Time of Arrival), TDoA (Time Difference of Arrival), AoA (Angle of Arrival), and RSS (Received Signal Strength) [7].

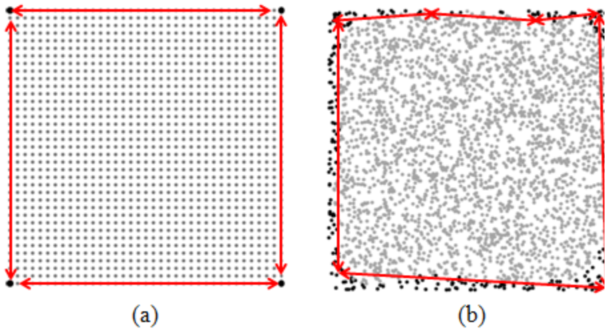


Fig.7. Distance estimation.

The best technique in order to obtain the better results in the distance estimations between the border nodes (Figure 7) is always an open research problem with a large number of parameters (e.g. transmission power, radio frequency, perturbations of the material…). In our case, it implies the study of the performances of these techniques. More particularly, in the case of distance estimation between the border nodes for planar surfaces without disruptions of the material (assumption 4).

To test the "distance estimation", we will develop a new chapter of "applications", in order to prove the different techniques of localization, and other parameters and relations like: the density of nodes with the accuracy, the perturbations of the material with the signal, the antenna capabilities etc.

IV. APPLICATION

The SMS strategy will be tested on different pieces of wood for construction materials, by deploying a wireless sensor network on the surface. The objective is to implement the neighborhood concept and test ranging techniques in order to estimate the product dimensions.

In the same time, other application is to test the communication capabilities between the products. Figure 8.a shows that the product is able to re-estimate their dimensions after the cutting process and Figure 8.b shows the communications capabilities between the two products in order to re-estimate the dimensions of both together.

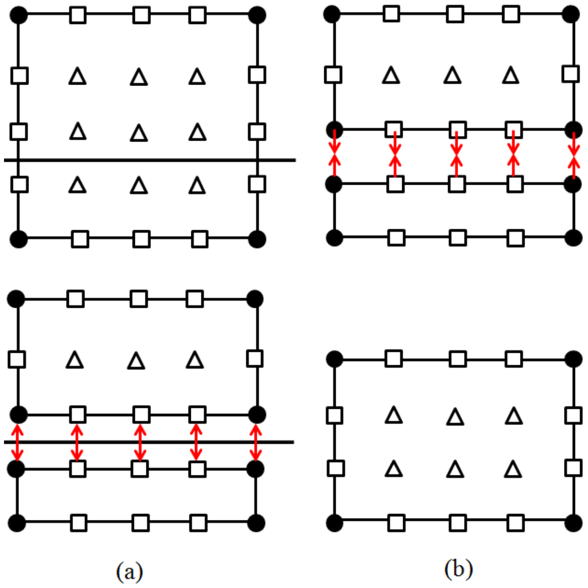


Fig.8. Communication capabilities.

CONCLUSION

Today there is an inverse relationship between flexibility (ability of the system to work in different environments and to perform various measurement tasks) and metrological performance (measurement characteristics in terms of stability, repeatability, reproducibility and accuracy) in the measurement systems of large size pieces. Systems like Laser Trackers, Laser Radars and Photogrametry have medium levels of flexibility, but high levels in terms of measurement characteristics. By contrast, other measurement systems such as indoor GPS, Theodolites, Total Stations, and MSCMS-I or II, have high levels of flexibility, but medium levels of accuracy [8], i.e. the balance between flexibility and precision is an unresolved issue.

The strategy SMS seeks to balance through of integrating the concept of wireless sensor networks (flexibility) for to endow with these the product materials (precision), in the direction to create intelligent products that are able to communicate their dimensions with the environment. But today there are many technological restrictions where it is necessary to have tiny sensors at very low cost, efficient communication skills that are not disturbed by any kind of material, and with energy consumption which allow at the product to perform the auto-measurement in any point during their life cycle. So in this first stage the objective was to present the outline of the strategy and its three main steps: to endow the product with a network of smart dust in the composition material, identify the nodes on the border of the material, and estimate the distance between them, in order that the product itself determines its dimensions.

For the first stage of this research, we work on the assumption that in the future will be possible integrated smart dust networks in the material composition of the products. On this basis, the deployment of a network on a simple shape (square) is presents. The test with simple decision rules permits to identify the border nodes, resulting a direct relationship between the density of nodes and the accuracy. Finally, this research is in testing phase to prove the effectiveness of different localization techniques in order to estimate the distance between the border nodes, through the deployment of wireless sensor networks on wood pieces.

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