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# *Wireless Sensor Networks Used in Quantum Measurement*

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***Keywords:*** Wireless sensor networks, quantum measurement, uncertainty principle

***Abstract:*** A new field in which wireless sensor networks (WSN) can be used is presented. In the microcosmic field, WSN meets great difficulties. In order to realize quantum measurement, we must consider Heisenberg's uncertainty principle. Besides, quantum measuring theory, quantum cloning theory and matrix mechanics should be taken into account. Finally we raise some possible solutions to make a try.

## 1. Introduction

Classical sensor networks are usually used to measure the position of a matter or a particle [1]. Sometimes if we want to measure the velocity, we need to measure two positions in the particle's route, and then divide the distance by time to obtain the average velocity. But when it comes to the microcosmic field like quantum systems and fiber gating sensors, great difficulties will come:

(1) From Heisenberg's uncertainty principle, it's impossible to measure the position and velocity (or the energy and time) precisely at the same time;

(2) It's impossible to measure two positions continuously, because one measurement may destroy the state of the system;

(3) If the state is destroyed, even the average of position and velocity will be impossible to measure.

For microcosmic measurement, even the 3 difficulties have been overcome, the measuring methods are still hard to design. A sensor is not enough, thus sensor networks are needed [2]. The present sensor networks are far from mature, so there's still a long way to go. This article will mainly discuss the quantum uncertainty effects in sensor networks, and raise some possible solutions.

## 2. Microcosmic Measuring Methods Using WSN

For macroscopical measurement, quantum uncertainty effects can be neglected. But for microcosmic measurement, quantum effects may be vital.

Consider a particle A with mass m, position x and momentum p. Here p and x are in the same direction. Our target is to measure x and p precisely at the same time. If at different time, the first measurement will destroy the state of the system, making the second measurement impossible.

Microcosmic particle's motion can only be measured by another microcosmic particle B. B can be regarded as a wave or a particle, so we'd discuss under 2 cases. For each case, the measured variable can be x or p, so there are altogether 4 cases. Let's discuss about them separately with table

1:

Table 1: Four cases of quantum measurement using WSN

| | |
|---|---|
| Case 1 | Use a wave to measure x |
| Case 2 | Use a wave to measure p |
| Case 3 | Use a particle to measure x |
| Case 4 | Use a particle to measure p |

## 2.1 Cases 1: Use a wave to measure x.

We can use figure 1 to depict this case:

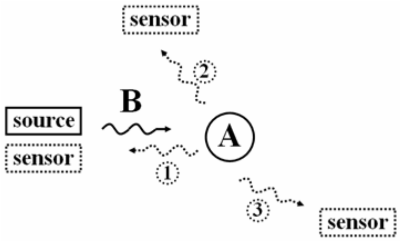


Figure 1: Use a wave B to measure x of A

A is the particle whose x and p are wanted. B is a wave coming from the source, which is a node of the WSN. After B touching A, B may reflect①, scatter② or circle around③. For each case, we can use a sensor to receive B. But it's usually impossible for B to go in only one direction. B may go in various directions much more than the 3 above. So in order to sense the entire motion of B after collision, we should use not only one sensor, but wireless sensor networks.

The following question is: how to use WSN to measure x of A? We can discuss about it under 3 cases.

① For reflecting, we can choose a sensor which can record the time when it receives a wave. If the source can record the time when it gives off the wave, we can use the change of time multiplying the velocity of the wave to obtain the distance between the source and A. Then x is half of this distance.

② For scattering, the sensor should record both the time when it receives the wave and the angle from the source to A to the sensor. Then we can use the change of time multiplying the velocity to obtain the distance. Now the angle and the distance from the source to the sensor are definite, so A has only 2 possible positions. Besides, A must be in the direction to which the source gives off the wave, and obviously it's impossible to find 2 positions in this direction that satisfy the same distance and angle, so we can choose the position which is in the direction the source gives off the wave. This is the required position x. Even when the source can't say clearly in which direction it gives out the wave, we can still use another sensor to obtain x.

③ For circling around, the diffraction image is relatively hard to describe. But in fact, we don't need to describe it clearly to obtain x. We only need to see where the distortion takes place. Whether the distortion is distinct or not, we can use some nodes to sense it.

Theoretically speaking, with the help of WSN, the 3 cases above can be solved easily. So it's easy to use a wave to measure x.

## 2.2 Cases 2: Use a wave to measure p.

How to use WSN to measure p of A?

If we assume B is a wave, we'll feel difficult to measure p. This is because, no matter what the velocity of A is, B’s velocity after collision will not change. For example, light can travel at the same speed c in the same medium, both before and after reflection or any other interaction. It is to say, as long as the position of A is definite when colliding, the results of measurement will be definite. The results won’t tell us the velocity of A.

So theoretically speaking, we can’t use a wave to measure p.

## 2.3 Cases 3: Use a particle to measure x.

In figure 1, if we replace the wave B by a particle B, two changes are as follows:

①The sensor can not only record the time when it receives the particle, but also the velocity when the particle comes to the sensor. This is because [3], a sensor in WSN should be able to record the energy it has received accurately to judge whether the accumulated energy is larger than the threshold. While in fact, in the quantum system, the energy a sensor receives equals the kinetic energy of the particle before it is received. So we can use the sensor of WSN to obtain the kinetic energy of the particle coming back.

②When particle B collides with A, B will destroy A’s initial state. If we regard B as a wave, this effect may be neglected. But when B is a particle, the heavier B is, the distinct the effect is.

Based on the two changes above, we can see that:

①The parameter measured can not only be those in case 1, but also can be the velocity of B after collision.

②The parameter to be measured can only be the variables of A before collision.

Above all, we can’t use a particle to measure x. On one hand, it’ll destroy the initial state. This will bring difficulties to continuous measurement. On the other hand, although it can measure the velocity of B after collision, it can’t measure B’s velocity before collision. This is because collision can change B’s velocity, and that’s the difference from wave. So the distance can’t be measured.

Theoretically speaking, we can’t use a particle to measure x.

## 2.4 Cases 4: Use a particle to measure p.

If the mass of A and B is known, we only need to measure the velocity of A to measure p. Assume A and B’s velocity is $\mathbf{v_A}$, $\mathbf{v_B}$ respectively before collision, and $\mathbf{v'_A}$, $\mathbf{v'_B}$ after collision like figure 2:

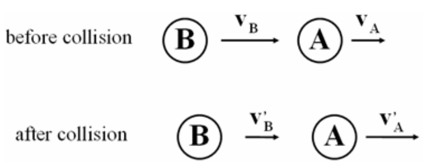


Figure 2: Velocities before and after collision

So elastic coefficient $\mathbf{e = \dfrac{v'_A - v'_B}{v_B - v_A}}$. When $\mathbf{v_A}$ increases, we can see $\mathbf{v'_B}$ will also increase from figure 3:

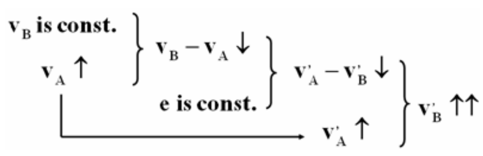


Figure 3: Relation between $\mathbf{v_A}$ and $\mathbf{v'_B}$

Now $V_A$ is the parameter to be measured, and $V'_B$ is the parameter measured. So we can use this method to measure p by measuring $V'_B$.

From all the discussions above we can see, a wave can only be used to measure x, and a particle can only be used to measure p. Next we'll discuss about how to measure both x and p.

## 3. Difficulties and Possible Solutions

It's easy to measure the position x for one time. But for continuous measurement, if we use a particle, the first measurement will destroy the initial state of the system. If we use a wave, the effect may not be so obvious. But if it can't be neglected, we won't be able to measure x continuously to measure p. In this case, we can only measure x and p for one time. It means, we should measure x and p at the same time. But from Heisenberg's uncertainty principle, this is impossible. This conclusion can be deduced from the following theorem.

**Theorem**: If $[\hat{A},\hat{B}]=i\hat{k}$, then $\overline{(\hat{A}-a)^2}\cdot\overline{(\hat{B}-b)^2}\geq \bar{k}^2/4, \forall a,b\in R$.

**Proof:** $\overline{(\hat{A}-a)^2}\cdot\overline{(\hat{B}-b)^2}\geq \bar{k}^2/4 \Leftrightarrow \forall x\in R, \overline{(\hat{A}-a)^2}x^2+\bar{k}x+\overline{(\hat{B}-b)^2}\geq 0$.

While $\overline{(\hat{A}-a)^2}x^2+\bar{k}x+\overline{(\hat{B}-b)^2}=\left[\int\psi^*(\hat{A}-a)^2\psi\right]x^2-i\left[\int\psi^*(\hat{A}\hat{B}-\hat{B}\hat{A})\psi\right]x+\left[\int\psi^*(\hat{B}-b)^2\psi\right]$

$$=\left[\int\psi^*(\hat{A}-a)^2\psi\right]x^2-i\left[\int\psi^*[(\hat{A}-a)(\hat{B}-b)-(\hat{B}-b)(\hat{A}-a)]\psi\right]x+\left[\int\psi^*(\hat{B}-b)^2\psi\right]$$

The integrated function is:

$$\left[(\hat{A}-a)\ \psi\right]^*\left[(\hat{A}-a)\ \psi\right]x^2-i\left[(\hat{A}-a)\ \psi\right]^*\left[(\hat{B}-b)\ \psi\right]x+i\left[(\hat{B}-b)\ \psi\right]^*\left[(\hat{A}-a)\ \psi\right]x+\left[(\hat{B}-b)\ \psi\right]^*\left[(\hat{B}-b)\ \psi\right]$$

$$=\left[\left[(\hat{A}-a)\ \psi\right]^*x+i\left[(\hat{B}-b)\ \psi\right]^*\right]\left[(\hat{A}-a)\ \psi x-i\,(\hat{B}-b)\ \psi\right]\geqslant 0$$

So the integration is no less than 0.

**Corollary:** Let $\Delta A=\overline{(\hat{A}-\bar{A})^2}$, then $\Delta x\cdot\Delta p_x\geq\frac{\hbar}{2}, \Delta E\cdot\Delta t\geq\frac{\hbar}{2}$.

In order to solve this problem, we can use quantum cloning. Since we can't measure a quantum system's x and p accurately at the same time, we can get a new system by cloning. Since the two systems are the same, we can measure the first system's x and the second system's p to get both x and p of the initial system at the same time. But cloning is against the linearity of quantum system, so quantum cloning is impossible. So we can consider approximate cloning or probability cloning. But another question comes, even if we can realize quantum cloning, we still can't measure x and p accurately at the same time. This is because, from quantum theory, measurement can make the quantum state collapse to stationary state. For x and p operator, their stationary states are different. If we measure the first system's x and the second system's p, we can't make sure that the two quantum state can collapse to the same stationary state. In order to make them collapse to the same stationary state, we should adjust the coefficients of superposition to make the probability of the desired stationary state larger[4].

## 4. Conclusion

We've discussed about the possible contributions of WSN to quantum measurement. Details are presented about the methods of measuring a microcosmic particle's position and velocity. We can see, we can use a wave to measure position, and we can use a particle to measure velocity. But the inverse is impossible. Then we've shown the possible methods to measure the position and velocity at the same time. But quantum cloning is still a long way to go. Accurate quantum measurement calls for not only WSN, but also efforts from all sides.

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