Network Beatles: A Distributed Wireless Network Platform for Tangible User Interfaces

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ABSTRACT

In this work, we are distributing the computing intelligence onto a set of tangible, wirelessly connected nodes able to autonomously find out their relative locations. We discuss the location sensing technique, which utilizes no special hardware but is based on power measurements of received signals at the infrared communication link between each pair of nodes.

The nodes are able to map out their physical topology and a simple demonstration is presented. Since topology of the nodes is found through networking, there is no need for specialized object tracking surfaces or other means of centralized location estimation hardware. Therefore the tabletop workspace area is limited only by the number of nodes used, opening new possibilities for large-surface Tangible user interfaces.

The nodes and their associated networking and sensing algorithms form the *Network Beatles* and their limitations are also discussed.

Keywords
Tangible user interface, interactive surface, object tracking, wireless networking

INTRODUCTION
Tabletop surfaces with mechanisms for input consist an essential functional element of Tangible user interfaces. Object tracking technologies based on sound and/or vision have been extensively utilized, however they are limited by the number of objects that can be tracked at each time point. Techniques based on electromagnetic coupling [3] are much more precise and robust and can be made to work for a larger than two number of users. However they are limited by the actual area of the sensing surface, limiting the overall workspace (and therefore number of users).
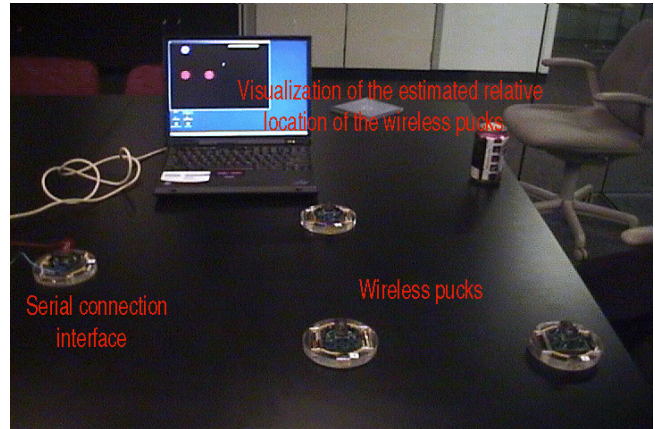

Figure 1. The wireless pucks estimate their relative location through the infrared communication link and fuse that information to the serial connection gateway.

APPROACH
In this work, we are trying to extend the workspace area roughly proportionally to the number of users and consequently, linearly with the number of tangible pucks being utilized. We equip each tangible puck with a micro-controller for computing capability and a set of eight infrared wireless transceivers, in octagonal setup. We create custom wireless and networking protocols that enable the transmission of information in a multi-hop way between any two pucks, through the network of pucks. The fundamental problem of sub-centimeter position estimation of the wireless pucks arise and we treat that successfully with power measurements of infrared signals, transmitted and received through the communication link. Therefore there is no need for additional sensors for position estimation. Since power measurements can give range estimation, triangulation between the nodes is employed for precise location estimation.

DESIGN OF NETWORK NODES
Before explaining the details of the position estimation technique and presenting an example, we should describe the hardware and algorithms employed.

Hardware and Software Infrastructure
The processing board of each puck is a Pushpin processing board [2] connected to an octagonal infrared transceiver designed at the Media & Networks Group. The processing

layer allows for the connection of eight or more analog inputs making possible the usage of each puck for a variety of input purposes.

One interesting addition was interfacing a small speaker at each puck and mapping range estimation between two pucks to different frequency tones (the smaller the distance the smaller the frequency). In that way, it was possible to test the granularity of the system and also find a funny way to map space to sound.

Custom routines for a 30kbps point-to-point link have been implemented and routing of information in a multi-hop packet based is utilized. Also there is technology for distributed time-synchronization [1] with sub-millisecond error. The pucks fuse their information packets to a similar node connected to the serial port of a pc [figure 2].
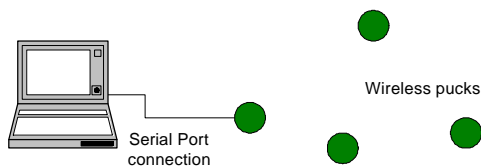

Figure 2. The experimental setup.

Position Estimation Technique

It is well known from the field of wireless communications that for constant transmitted power P_{TX} the received power P_{RX} is inversely proportionally to a power of distance:

$$P_{RX} = a\, P_{TX} / d^V$$

where a,v are constants depended on the medium between transmitter and receiver (as well as on the hardware of each transceiver) and d is the distance between transmitter and receiver. The parameters a, v can be found for a variety of scenarios and stored at each pack. The receiver then can measure P_{TX} and by knowing P_{RX}, then it can infer distance d from the transmitter. The only limitation here is that the two infrared transceivers (transmitter and receiver) should be aligned. Alignment can happen through sound since misalignment is translated to smaller received power, which is mapped to higher frequency tones. A simple manual rotation of either transmitter or receiver could solve this problem (since the audio frequency indicates strength of received signal and therefore alignment).

Mapping Physical Topology in Real Time

A simple demonstration of the above ideas was implemented [Figure 1]. Three nodes equipped with buttons could triangulate and fuse wirelessly that information to a fourth node connected to the serial port of a pc. The typical sequence for a single measurement was: transmitter starts transmitting constant power pulses ⇒ receiver starts receiving pulses ⇒ receiver measures received power and stops receiving ⇒ transmitter stops transmitting pulses and sends a data packet informing the receiver about its ID ⇒ receiver received the ID data packet and assemblies a new data packet with the range estimation information and the pair of transmitter and receiver ID's (alongside with other necessary networking information). The data packet is relayed to the gateway and from there to the pc and the distance between transmitter and receiver is visualized.

The usage of buttons was preferred for demonstration purposes. The whole scheme could be automated in a circular round-robin fashion for each pair of pucks, since each range measurement can be done within ¼ of a millisecond (or less).

ADVANTAGES

The treatment of location sensing as a networking problem, eventually solves the problem of limited area workspace in a tangible user interface and increases the area linearly with the number of tangible pucks. This fact opens exciting new possibilities for multi-people collaboration in tangible user interfaces.

LIMITATIONS

Since the problem of distributed location estimation has been transformed to a networking problem, all the limitations in scalability of wireless networks might arise. However, in the TUI case, the communication demands are moderate and therefore scalability might not be a problem.

The biggest concern in the current demonstration is the rotational variance in the measurements (misalignment). This can be solved with differential reception and that basically means that a secondary tier of eight more transceivers in $360/8/2 = 22.5^{o}$ shifted in relation with the first primal tier of transceivers should be used. Alternatively, an omni directional infrared transceiver could be built.

FUTURE WORK

Exciting new possibilities for multi-user collaboration in a common, unrestricted in size physical area arise. Future work should focus on application of the technology described above.

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