713. Indoor positioning using symmetric double-sided two-way ranging in a welding hall

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Abstract. We introduce a method by which to locate sensors in a 2.4 GHz wireless network. We tested our system in a rough welding hall, where plasma cutters and welding machines commonly cause radio interference. Indoor positioning is a challenge because standardized GPS-type global-positioning technologies are not available. There is therefore a need for extra infrastructure, such as wireless sensors, but moreover there is no standardized communication between sensors. Therefore, it is reasonable to investigate alternative technologies. We found that a reliable positioning system could be created by using Chirp Spread Spectrum (CSS) modulation. Also, we studied which CSS parameters affect the transfer data rate in order to determine the most reliable speed for both top and average transfer.

Keywords: indoor positioning, wireless sensor network.

Introduction

Data throughput speed is a compromise between the frequency bandwidth and the channel use time. Determining a reliable combination of these helps to prevent collisions on wireless channels and increases the total data-transfer capacity of the machines. A couple of different methods can be used with indoor positioning methods. For example, Alippi et al. [1] used RFID tag readers to cover the area of tag movement with an accuracy of about 0.6 m when the readers are less than 3 m apart. Radio positioning systems are used in many ways. The Chirp Spread Spectrum (CSS) signal was used successfully by Huang et al. [2] to compensate for positioning errors in low-noise conditions (signal to noise ratio, SNR, below –20 dB), resulting in a resolution of better than 1 m. Still, there is a need to synchronize the clock between the transmitter and the receiver. Yoon et al. [3] generated an anchor-free positioning system by using CSS radios, showing that there is no need to provide an anchor. This is because the networks locate themselves and a mobile phone is used as a gateway to collect nearby location information. In this way the system builds up time and costs will decrease, increasing its potential for use. Robust outdoor localization methods have been presented by Stoleru et al. [4] and Murty et al. [5]. Some of these principles are also valid for the coarse indoor localization of mobile machines.

Our studies on the remote navigation of mobile robots focused on improving the accuracy of indoor positioning. In earlier studies performed by us [6], we found that WLAN- and ZigBee-based positioning systems are unsuitable for remote navigation. Based on a literature review, we believe that UWB positioning is a promising technology, although penetrating metal surfaces is still challenging [7]. We used CSS radios, which use a given bandwidth and a progressively increasing frequency, as an “up-chirp” in this study. Based on our previous results this seems to be more suitable and reliable for indoor positioning in the metal industry than is the Received Signal Strength Indication (RSSI) method [15]. Because of a relatively large bandwidth (80 MHz), CSS pulses are insensitive to electromagnetic distortion and do not experience multipath fading. In addition, CSS is able to utilize RF echoes when calculating distances. Distance calculation could proceed during normal data transfer, or the radio could be programmed with a special ranging mode, when the whole bandwidth is used for positioning purposes. Both radios send two messages: a data question and a response. As a result, by using signal propagation and processing delays the range between the radios could be calculated.

Transfer speed here means the average data rate on the channel. We also recorded the maximum data rate during our measurements. Message length affects transfer speed, and when more data are included, such as one frame and one header, more data are transferred. The bandwidth could be set at 22 or 80 MHz, but larger bandwidth causes interference with other ISM-transmitters, such as WLANs in the same area, although this should provide higher data rates. This method might not be able to be used in all environments. The radio used provides a special high data rate mode, where the positioning capabilities are reduced and more time is required for data transfer.

Experiments

In indoor conditions, where many reflecting and conducting materials are nearby, multipath propagation causes errors in estimating the distance between radios. This is because radio waves reach the receiver along different pathways and the measurable distance varies when the measurements are repeated. The rough conditions inside a metal factory present additional challenges for radio-frequency positioning systems. Steel walls, plates in storage areas, and sheet metal stacks cause reflections and prevent line-of-sight propagation of the signal. Welding machines and plasma cutters cause noise within and interference between radio waves. Most of the received signals are reflected and a straight route near the floor cannot be used.

These conditions cause radio wave fading and reflections. Also, local, stronger values could be collected when reflected waves in the same phase reach the receiver, causing the estimates of distance to be too small. This seems to be common in our measurements inside a factory. We conducted our positioning measurements in a metal factory welding hall during the normal activities of the business. There were eight operating welding machines in the hall. Our test environment is illustrated in Figure 1. As shown, there were obstacles along the routes between node AP1–TAG (lift truck) and node TAG–AP2 (shelf).

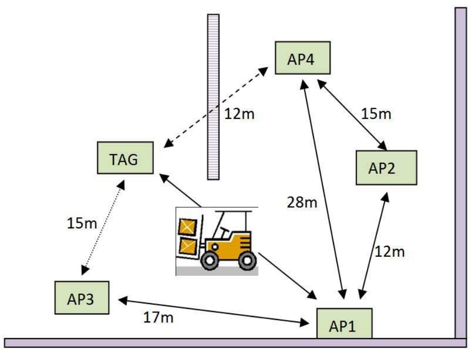


Fig. 1. Radios and obstacles in our welding hall test environment

Positioning measurements

We installed five radio nodes, denoted as AP1–AP4 and TAG. After installation, we confirmed that all of the radios were able to communicate and measured their actual distances by using a steel meter stick. The distances are shown in Table 1.

Table 1. Actual distances (m) between nodes

AP1 to AP2	AP1 to AP3	AP1 to AP4	AP1 to TAG	AP2 to AP3	AP2 to AP4	AP2 to TAG	AP3 to AP4	AP3 to TAG	AP4 to TAG
12.0	17.5	27.6	18.7	18.5	15.0	9.2	28.1	15.3	12.5

We used several parameters of our user interface to determine how distances should be measured. The first distance could be the average, minimum, or maximum values of the last measurement. We recognized that some spans make the nodes appear to be farther apart while other spans make the nodes appear closer together. We gave both kinds of spans different multipliers for the change in their influence on the calculated distances. Table 2 provides the distance measurements based on the average of the last 50 values.

Table 2. Average values of the calculated distances (m) between nodes

AP1 to AP2	AP1 to AP3	AP1 to AP4	AP1 to TAG	AP2 to AP3	AP2 to AP4	AP2 to TAG	AP3 to AP4	AP3 to TAG	AP4 to TAG
13.6	19.7	29.5	23.2	23.4	17.5	29.4	30.1	18.9	14.2
13.8	19.6	29.5	21.9	22.9	17.6	32.1	32.3	25.4	14.2

All of the calculated values are larger than the actual ones. Barriers between nodes completely eliminate line-of-sight waves. This means that even the fastest waves were reflected around surfaces, leading to a larger than actual calculated distance. Even worse results were observed when a larger effect was given to pushing spans. For this reason we decided not to use the maximum measured values. We calculated the error percentage between the calculated and measured values (Table 3).

Table 3. Error percentage of the average values versus actual distances

AP1 to AP2	AP1 to AP3	AP1 to AP4	AP1 to TAG	AP2 to AP3	AP2 to AP4	AP2 to TAG	AP3 to AP4	AP3 to TAG	AP4 to TAG
15.0	12.0	6.9	17.1	23.8	17.3	248.9	14.9	66.0	13.6
13.3	12.6	6.9	24.1	26.5	16.7	219.6	7.1	23.5	13.6

The shelf between TAG and AP2 blocked the waves, and there was no room to propagate the signal under the shelf. The connection between nodes was established through the ceiling and adds 20 m to the distance. We chose the minimum distance of the last measurement for each span, again using multipliers. In Table 4, we increased the shortened multiplier.

Table 4. Calculated distances based on minimum values

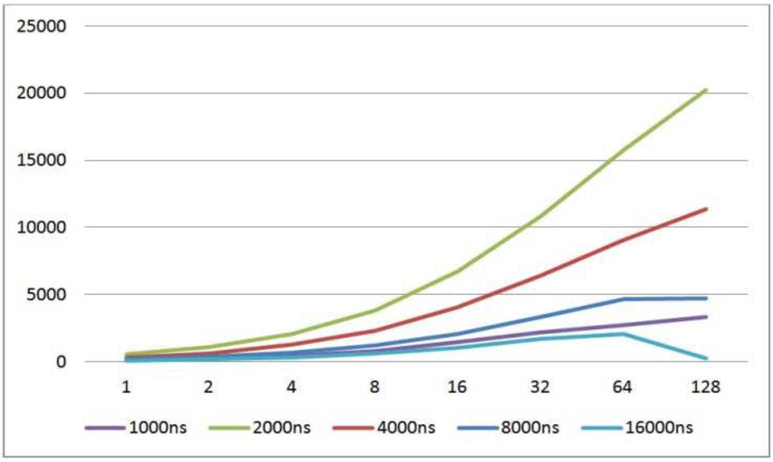
AP1 to AP2	AP1 to AP3	AP1 to AP4	AP1 to TAG	AP2 to AP3	AP2 to AP4	AP2 to TAG	AP3 to AP4	AP3 to TAG	AP4 to TAG
12.8	19.2	28.9	20.7	21.8	16.9	31.3	29.6	29.6	13.5
13.2	18.6	28.9	20.5	20.2	16.9	12.8	29.7	23.2	13.7
12.4	19.2	28.4	20.5	19.5	16.9	16.9	29.5	26.8	13.7
12.9	19.1	28.8	20.8	21.8	16.9	31.0	29.5	26.8	13.6

The calculated distances varied for span AP2–TAG. Sometimes waves could penetrate parcels on the shelf and in those cases the distance is nearly correct. When this happens is not easy to predict because all of the nodes were stable and untouched during all measurements. Perhaps the nearby plasma cutter reflected or weakened the waves enough to prevent penetration through the shelf. The cutter was active continuously during the measurements, but there were small breaks between the moving head and the steel plate.

Data Rate Measurements

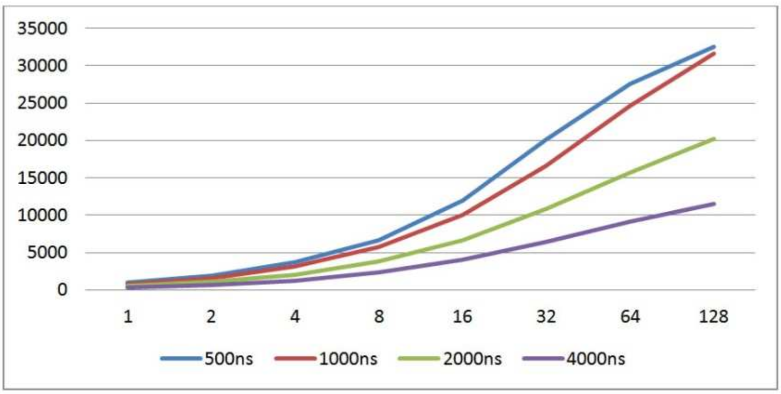
We collected the data throughput measurements under different conditions. At the larger scale, we adjusted bandwidth to between 22 and 80 MHz. We then adjusted the bitrate to between 1000 and 16000 ns. These measurements were conducted with different message lengths of between 1 and 128 bytes. We measured the average data throughput speed between two nodes and the line-of-sight span.

We started with the 22-MHz bandwidth, and the data rates (in bytes per second) are shown in Graph 1.



Graph 1. Data rates at 22 MHz bandwidth

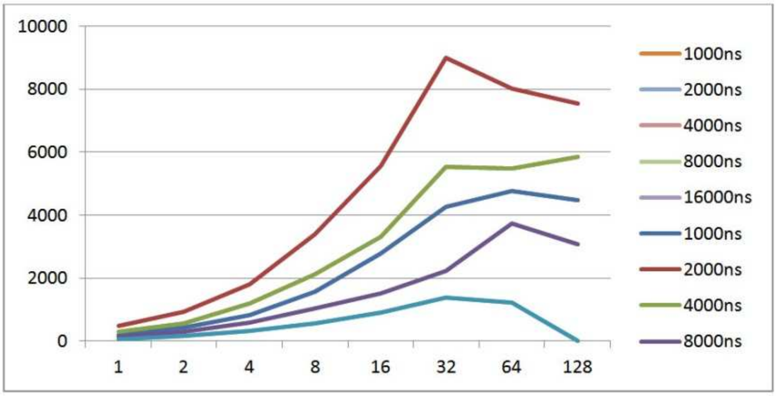
Shorter bitrates provide higher data speed. However, if the rate is too short (1000 ns here) the transfer speed drops dramatically. As expected, longer messages give a better overall data rate. The relative parts of the frame headers stay small and more of the entire bandwidth is used for the actual data. The exception here was with 16000 ns, where the 128-byte data were too long to reach the receiver. Based on these results, we tested a higher bandwidth with a relatively short bitrate. This time we started as low as 500 ns and proceeded to 4000 ns to see if we could get even higher speeds. Graph 2 provides the data rates (in bytes per second) when the entire 80-MHz frequency range was used.



Graph 2. Data rates at 80MHz bandwidth

As expected, shortening the bit rate and lengthening the message gives a larger data rate. Saturation of the rate was encountered with the shortest bitrate (500 ns). A comparison between the different bandwidths could be made with bitrates from 1000 to 4000 ns. At 2000 ns the larger bandwidth did not help any, and we obtained almost the same data rates at both 22 and 80 MHz. High bandwidth provides better results and we succeeded in obtaining over 30000 ns.

We used 22 MHz to test how the presence of one wall between two nodes affects the data rate. As shown in Graph 3, transmission failures with longer message lengths dramatically reduce the average speed. Packets reattempts are easily seen here at average speeds. When there are obstacles along the transmission route, the packet length should be limited to 32 bytes in order to optimize performance.



Graph 3. Data rates at 22MHz bandwidth through a wall

Conclusions

Positioning was quite reliable by using this method. Low impact of pushing longer multiplier and higher impact for shorter multipliers give better results. Barrels blocks usually waves totally. Sometimes occasionally, waves could access without reason barrel. We never estimated distances that were lower than the actual distances.

The use of a wider bandwidth or a shorter symbol increases the throughput data rate. The data rate seems to remain stable and there were only minor variations during the measurement period. Walls and obstacles along the transmission route cause transmission reattempts and significantly decrease the data rate if message lengths over 32 bits are used. Narrowband communication has more distortion than does wideband when obstacles are located along the line of sight. By choosing the wideband transmission mode and a short symbol length, the effect of obstacles along the route could be minimized.

By comparing results, this positioning method provided longer than actual distances. We suppose this occurs because of delays in the processor when processing times are very short. Very good accuracy will be observed when several measurements are minimized. In this way we observed distances about 12% longer than the actual distances, and this is easy to compensate for by using software. The longest connection inside the welding process hall was 56 m. One sheet metal wall was within a shorter range of 43 meters. We were unable to estimate distances through the outer wall.

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