Weld Gun Spatial Tracking System

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1. Introduction

1.1 Objective

In the future, there will be a shortage of 200,000 welder operators over the next 20 years. Potential workers need a lot of time of training in order to be skillful, which is a significant cost in the industries. To speed up the training process, orientation tracking of weld gun in three-dimensional space is crucial to measure the postures of training welders.

We propose to construct a spatial tracking system to locate a single point on the weld gun in a 10 x 10 x 10 feet space. The system consists of one beacon component and four listener components. The beacon is attached on the weld gun which represents the single point to be tracked. The beacon sends out ultrasonic signal and radio frequency signal simultaneously at 25 samples per second (time frame = 40 ms). The four listeners are placed on the corners of a square with side length 10 feet. Each listen component measures the time delay between the receiving radio frequency signal and an ultrasonic signal and calculates corresponding travel distance between the beacon and the listener. One host (PC) receives four distance values between the beacon and each listener through WIFI communication. It then calculates the three-dimensional coordinate of the beacon and displays it on the screen.

1.2 Background

Measuring the posture of training welders can help get the new hire up to speed in a production environment. Global navigation satellite system (GPS) is widely used for position in space. However, it usually fails to track points accurately in an indoor environment because of interference of signal from roofs and walls. Our solution, which utilizes both ultrasonic signal and radio frequency signal, provides accurate measurement of a single point inside a 10x10x10 feet space. The system contains one beacon component, which represents the point we target to track. More beacon components can be implemented in the future in order to track multiple points so the orientation of the weld gun can be visualized.

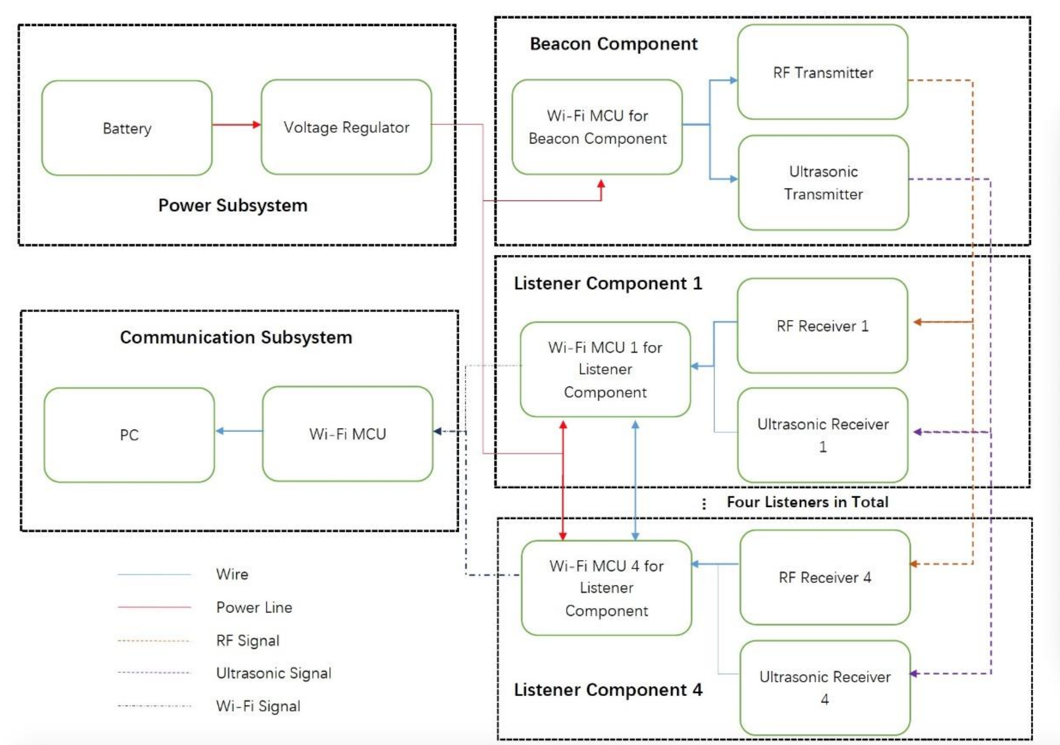
Weld posture is the orientation of the weld gun relative to the workpiece. The workpiece can be welded adequately if the welder uses a weld gun at the proper work and gun angles. After successfully measure the orientation of a weld gun in space, information such as distance from a weld gun to the workpiece, weld gun orientational angle, and travel speed can be obtained through mathematical computation. We believe that our system is the initial step of the digitalization of weld gun training process. Its impact includes improving the efficiency of welding training process and reducing industries cost.

1.3 High Level Requirement List

- The beacon component must be able to send ultrasonic signal and radio frequency signal simultaneously at 25 HZ, and the listener components must be able to receive these signals at 25 HZ.
- The four listener components must be able to operate synchronously and send data to the host at the same time.
- The result of the coordinate of one single point must be within 10 mm accuracy.

2. Design

2.1 Block Diagram

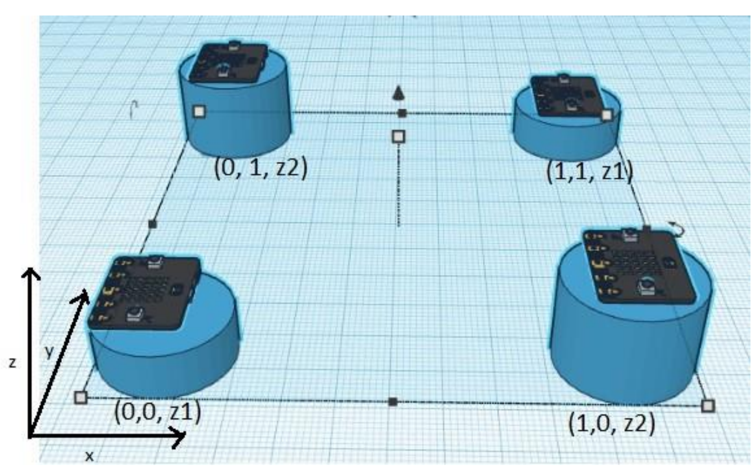


The four primary subsystems in our design are the power subsystem, the beacon component, listener component (x4), and the communication subsystem. Power is supplied to microcontrollers in beacon and listener components through voltage regulators and battery. The beacon which is mounted on the weld gun emits RF signals and ultrasonic signals simultaneously at 25 HZ to the receivers in the listeners. The microcontroller in the listeners measure the time delay between RF and ultrasonic signals and calculate the distances from the beacon. The four listener components operate and then transmit the respective distance information to the host PC via a Wi-Fi connection. The Communication subsystem transfers the data from four listeners to the host PC which computes the coordinates of the beacon and display result on screen.

Radio frequency signal travels at the speed of light, while the ultrasonic signal travels at 430 m/s. The listener receives a radio frequency signal earlier than the ultrasonic signal. Suppose the radio frequency signal arrives at the listener at t1, and the ultrasonic signal arrives at the listener at t2. Distance (d) between the beacon and the listener can be solved by the following equation. C is the speed of light [7].

$$d / 430 - d / c = t2 - t1$$

2.2 Physical Design



The system consists of one beacon component, four listener components, and one host for computation. In the diagram, the four listeners are located at the four corners of a square with side length 10 feet. Their coordinates are shown. The two listeners in the diagonal have the same height. Suppose the coordinates for the four listeners are (0, 0, z1), (0, 1, z2), (1, 0, z2), (1, 1, z1), and the distance from the beacon to the four listeners are d1, d2, d3, d4 respectively.[4] The beacon is placed inside the square, and let the its coordinate be (u,v,w). We can establish the following equations. Equation 1, 2, 3 are used to solve for u, v, w, and Equation 4 is used to check error rate. The calculation is done on a host which stores the known coordinates of each listener and receive distance values through Wi-Fi communication.

$$d1 = \sqrt{u^2 + v^2 + (w - z1)^2} \qquad equation\ 1$$

$$d2 = \sqrt{u^2 + (v - 1)^2 + (w - z2)^2} \qquad equation\ 2$$

$$d3 = \sqrt{(u - 1)^2 + v^2 + (w - z1)^2} \qquad equation\ 3$$

$$d4 = \sqrt{(u - 1)^2 + (v - 1)^2 + (w - z2)^2} \qquad equation\ 4$$

2.3 Functional Overview

- **Power Subsystem**

Individual power subsystem is implemented to provide power to each component such as beacon and listener. The voltage output is 3.3 V which is the power requirement of the microcontroller.

  - Battery

    Function & Role: Serves as power source

  - Regulator

Function & Role: Stabilizes voltage and constraints power output value

- **Beacon Component**

  Beacon component sends the radio frequency signal and ultrasonic signal simultaneously at 25 samples per second. It represents the single point which is targeted to track in three-dimensional space.

  - Ultrasonic transmitter

    Function: Emits ultrasonic signal

    Role: Sensor

  - Radio Frequency transmitter

    Function: Emits radio frequency signal

    Role: Sensor

  - Wi-fi microcontroller

    Function: Controls the ultrasonic transmitter and radio frequency at the desired frequency (25 Hz), and synchronizes with listener components

    Role: Processor

- **Listener Component**

  The Listener component receives the radio frequency signal and an ultrasonic signal, calculates the distance between the beacon and the listener based on the time delay between the two signals.

  - Ultrasonic receiver

    Function: Receives ultrasonic signal

    Role: Sensor

  - Radio Frequency receiver

    Function: Receives radio frequency signal

    Role: Sensor

  - Wi-Fi microcontroller

    Function: Measures the time delay between the radio frequency signal and an ultrasonic signal and calculates the distance. Wi-Fi communication is used to synchronize with other listener components and beacon component and sends 25 samples of distance value to the host per second

    Role: Processor

- **Communication Subsystem**

  The Communication Subsystem is the destination of the system. It receives one set of the data packet (four pairs of distance values and listener ID). The PC receives the data and computes the coordinate of the beacon. The coordinate refreshes 5 times every second, which means that each display result is obtained by applying a filter to 5 set of samples (25 samples /second / 5).

  - Wi-Fi microcontroller

    Function: Receives data packet from four listener components, and sends data to PC through the wire connection [6]

    Role: Processor

  - PC host

    Function: Calculates the coordinate of the beacon and display results on screen

    Role: Processor

2.4 Block Requirement

	Requirement	Verification
Power Subsystem	Stable power supply at a voltage within a range of 3.3 ± 0.1 V	Connect the power unit to an oscilloscope, ensuring the output voltage is 3.3 ± 0.1 V
Beacon Component	Sends the radio frequency signal and ultrasonic signal simultaneously at 25 samples per second	Use the counter variable to count the number of samples sent in one second
Listener Component	Successfully receives each sample signal	Use the counter variable to count the number of samples received
	measures the time delay in a precision of microseconds	Print timestamp values on host PC to check
	Synchronizes with other listener components so that data in the same time frame are sent simultaneously to the Communication Subsystem	Store each sample data in the memory, and compare the number of samples in each listener component in a fixed time
Host PC	Successfully receive data from four listener components, and none of the samples is lost during communication	Print all sample data on the Host PC to check
	The accuracy of the beacon coordinate is within 10 mm in each dimension and the Host PC can display the 3D coordinate point synchronously	Use Programmable robot arm or motion capture camera to measure the location of the beacon, and compare it to our coordinate

2.5 Risk Analysis

Wave interference between signals in space could be a significant risk to the successful completion of our project. The signals we will be using in our design are RF signals and ultrasonic signals. Because of the use of wireless transmission, it is quite necessary to consider whether there will be interference between these two signals and other technologies in the working area such as a Wi-Fi router. Some potential risks of wave interference include signal lost, incorrect signals being received and processed by listeners, and unwanted noise produced. Therefore, we need to make sure the frequency of waves is adjusted properly to minimize this risk.

In addition, data synchronization is crucial to the accuracy of the calculation of distance and coordinate. If each listener component operates in their separate time frame and sends data non-simultaneously to the communication subsystem, data indicating the distance from different time frame might be used to generate an erroneous coordinate of the weld gun. Hence, time synchronization must be achieved within the four listener components.

Another issue that may affect the precision of the result is the time measurement while the time delay is measured in listener components after they received the RF and ultrasonic signals. It is straightforward to understand that precise measurement of time is directly related to the correct calculation of time delay and distance. Since our project requires a very accurate coordinate system to assist users to adjust the posture of weld guns, even an extremely tiny inaccuracy could possibly lead to a big difference between the real position and the displayed coordinate. If users adjust the posture of welding by using the inaccurate coordinate as a reference, serious incidents would occur including electric shock, hazardous fumes, and gases, fire, and explosions. Thus, an efficient and effective timing method and a system must be adopted such as RTC (Real Time Clock).

3. Ethnics and Safety

We know that ethics and safety are key to the successful completion of our project and we will try our best to ensure the ethics and safety of our project. Our project can have several potential safety issues. The power supply may get overheated and explode if the voltage is above the threshold voltage. The lithium battery will also lead to thermal runaway and fire if its temperature reaches above 355 Degrees Fahrenheit [1]. As #1 of IEEE Code of Ethics states: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices and to disclose promptly factors that might endanger the public or the environment” [2]. We will connect the power unit to an oscilloscope to closely monitor the voltages of the power supply and all other units.

RF Radiation from the beacon component may also cause an invisible hazard to the human body at high levels [3], but our system only contains one RF emitter which can produce a very limited amount of RF Radiation. Even though the radiation risk of our system is very low, we will still create protective measures for RF Radiation.

Last but not least, we honestly seek and accept technical advice to keep improving our system design following #7 of IEEE Code of Ethics: “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others” [2]. We respect the contributions of others by giving credits to works from others.

4. References

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