# Directional of Arrival Tag Response for Reverse RFID Localization

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***Abstract*—A positioning system implemented with RFID technology is explored for a GPS-denied environment such as an underground mine or tunnel. A new method of two-dimensional localization is developed based on the angles of arrival of three tag's responses that are located at known positions. This method reduces the error when the localization process is based on the received signal strength from an RFID tag signal. Passive tags are placed in predefined locations with known information about their coordinates. An RFID reader attached to a robot with a directive antenna is used to get the AOA of the signals received from the tags. The AOA information is then used for triangulating the position of a reader's location (reverse localization).**

***Keywords—Localization, RFID.***

## I. INTRODUCTION

Respirable dust is a known health hazard in underground mines and tunnels as well as in surface quarries and construction sites. To better track respirable dust exposure, a dust monitor with geolocating capabilities can be used to map dust exposure in spatial-temporal environment to improve engineering and management solutions for mines and industrial plant dust control.

For surface mines or other outdoor applications, the dust monitor can be equipped with a global positioning system (GPS). GPS is easily applicable, but it does not work in underground mine or tunnel environments. In such GPS-denied conditions, RFID locating technology can be used instead. RFID has been gaining popularity for its low cost compared to other locating methods. For this project, a systematic approach to locating an RFID reader using the signal strength and direction of three independent tags is developed.

## II. LOCALIZATION USING DISTANCE APPROXIMATIONS

### A. Mathematical Theory

The 2-D position of an unknown point can be discovered by knowing the position (x and y coordinates) of 3 different points and the distances to each of these points. Fig. 1 shows 3 circles whose radii correspond to the signal travel distance from the RFID tag to the unknown reader location. The intersections of any two circles determines the possible positions, usually 2, of the point with unknown coordinates. The intersection of all three circles then defines the exact coordinates of the unknown location. The $x_1$, $y_1$, $x_2$, $y_2$, $x_3$, $y_3$ are the known coordinates of points 1, 2, and 3 with $r_1$, $r_2$, and $r_3$ being the known distances away from point P with unknown coordinates x, y and z:

$$(x-x_1)^2+(y-y_1)^2=r_1^2,\quad (x-x_2)^2+(y-y_2)^2=r_2^2,\quad (x-x_3)^2+(y-y_3)^2=r_3^2.$$

As an example, consider the set of points P1, P2, P3 with coordinates (1,1), (6,3), (0,9) that are at distances of $r_1 = 7.2$, $r_2 = 4.1$, $r_3 = 5.4$ units away from the unknown point P. The unknown coordinates of point P can be found from the intersection of the circles as shown in Fig. 1 to be at location (5,7).

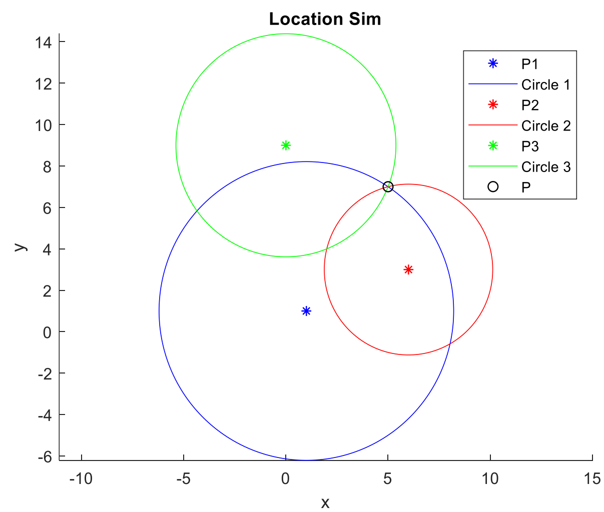


Fig. 1. A set of points P1, P2, P3 with known coordinates and the interesecting circles determining the coordinate of point P.

### B. RFID Implementation

In this project, ultra-high frequency (UHF) passive RFID tags are placed at known locations as reference tags to locate the RFID reader position. The reader uses an omnidirectional antenna that will record the received signal from a tag in terms of the received signal strength (RSS). Distances between the reader and the tags can be calculated from RSS values via a generated empirical function. The reader will continuously scan all nearby tags for a predetermined amount of time. Multiple readings from each tag are averaged to reduce error from extraneous readings. If echoes from more than three tags are received, the three tags with the greatest signal strengths are chosen for the coordinate triangulation.

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### C. Errors and Limitations

As Fig. 2 shows, even in a clean laboratory environment the RSS-distance relation is not smooth and will produce calculation errors. Note that this data set will not result in a function because there exist many instances where a single RSS value corresponds to more than one distance.

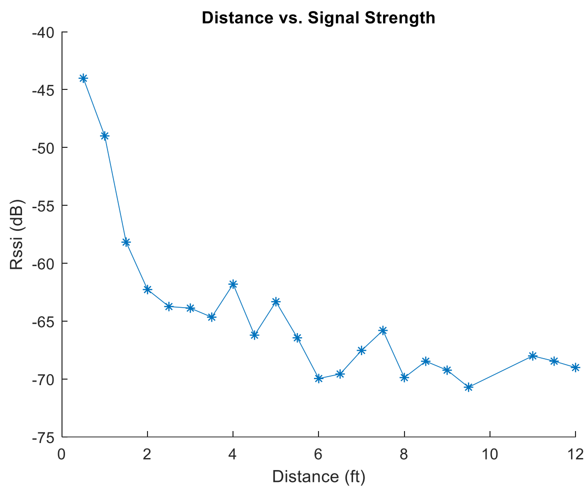


Fig. 2. Sample data showing how RSS varies greatly relative to distance.

In an underground mine environment, there may be metallic objects and electromagnetic noise that could create further interference and echoes that further distort the direct line of sight, RSS-distance relationship. Initial laboratory tests showed that location through RSS alone would not provide the desired level of accuracy. The authors decided to refine the triangulation algorithm and to improve its accuracy by recording the angle of arrival (AOA) of the received signal along with the RSS.

## III. LOCALIZATION USING ANGLE OF ARRIVAL

### A. Mathematial Theory

The directional algorithm similarly requires a minimum of 3 readings from the three known position tags to properly locate the unknown position of the reader. Instead of using the distance information, the reader records the AOA of the strongest signal from the known position tags. The reader must be equipped with a directional antenna which typically has a higher gain compared to the traditional omni-directional antennas, to improve the read range.

Fig. 3 illustrates the AOA from the three tags, the coordinates of the three tags and other parameters to use for solving for the unknown distances $r_1$, $r_2$, and $r_3$ using the following 9 equations:

$$\frac{d_{21}}{\sin(a_{21})}=\frac{r_1}{\sin(a_2)},\quad \frac{d_{21}}{\sin(a_{21})}=\frac{r_2}{\sin(a_1)},\quad \frac{d_{32}}{\sin(a_{32})}=\frac{r_2}{\sin(b_3)},$$

$$\frac{d_{32}}{\sin(a_{32})}=\frac{r_3}{\sin(b_2)},\quad \frac{d_{13}}{\sin(a_{13})}=\frac{r_3}{\sin(c_1)},\quad \frac{d_{13}}{\sin(a_{13})}=\frac{r_1}{\sin(c_3)},$$

$$d_{32}^2=d_{21}^2+d_{13}^2-2d_{21}d_{13}\cos(a_1+c_1),\quad d_{13}^2=d_{32}^2+d_{21}^2-2d_{32}d_{21}\cos(b_2+a_2),$$

$$d_{23}^2=d_{13}^2+d_{21}^2-2d_{13}d_{21}\cos(c_3+b_3).$$

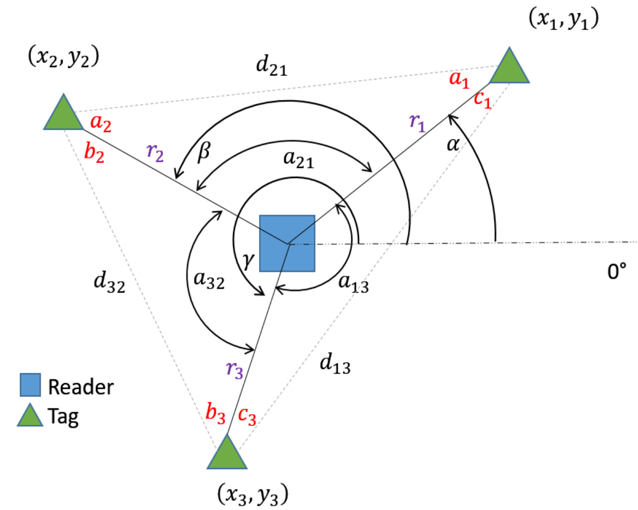


Fig. 3. The known variables in this system. α, β, γ are angles measured from the coordinate system zero axis represented by the dashed line.

Using $r_1$, $r_2$, and $r_3$ locating the unknown position of the reader can be achieved by the triangulation method described in Section II. For example, given a set of points P1, P2, P3 with coordinates (3,0), (12,1), (5,8) that are at angle of α = 213°, β = 351°, γ = 99°, the unknown reader position can be found from the intersection of the circles to be at location (6,2).

### B. Implementation

The algorithm based on the AOA estimation requires the use of a rotating directional antenna. The antenna will rotate 360 degrees at a fixed angular velocity while recording RSS values of all tags it finds. AOA values will be registered where the strongest signals (RSS values) are obtained along with the corresponding, calculated antenna direction. The triangulation algorithm will be applied to the three strongest readings to determine the reader location.

## IV. CONCLUSION

This implementation will be less susceptible to RSS variability caused by signal reflections off surrounding objects. Even though the reader will continue to detect those readings, the maximum RSS will be obtained from a direct line of sight with the tag which will be the strongest signal reflected from the tag. Thus, the accuracy of determining the distances is greatly enhanced. Further advantage of this process is the use of a directive antenna which will have a much greater range than an omni-directional antenna. This will also minimize the number of tags that are required and maximize the area in which the reader can detect itself. The biggest limitation however, for this algorithm is coordinates of the unknown reader position need to be within the triangle that is made by the three tags with known positions. However, for the localization of operators inside mines carrying a portable RFID reader, this special condition will not exist, hence this procedure would be applicable.