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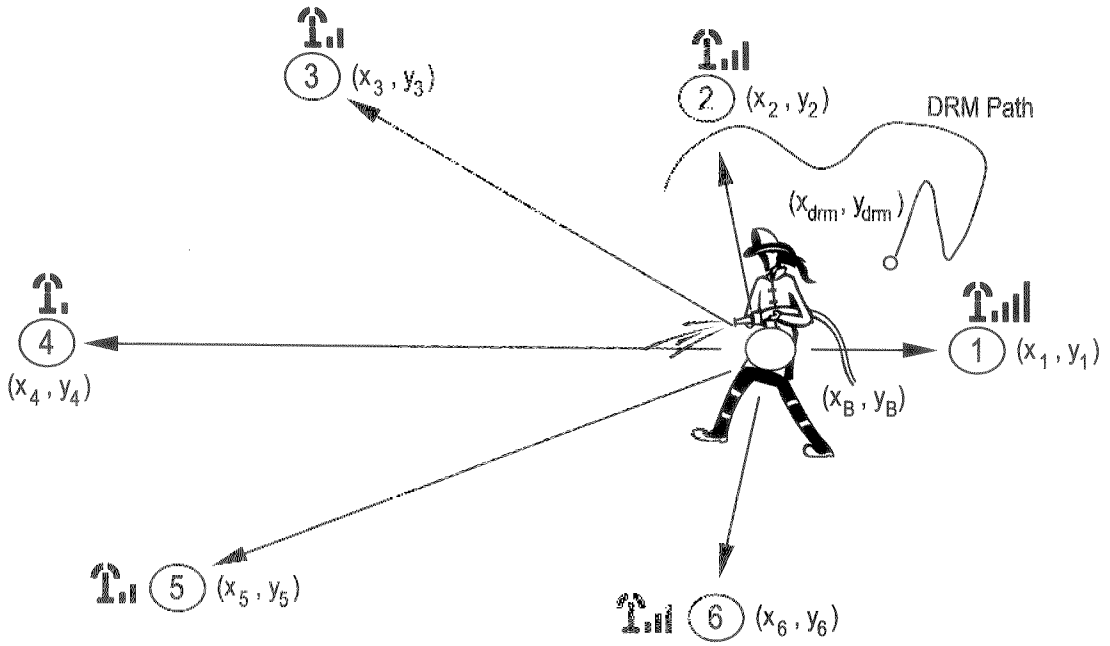
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(54) **Title:** LOCATION AND TRACKING OF PEOPLE WITH COMBINED USE OF RF INFRASCTURE AND DEAD RECKONING MODULES



(57) **Abstract:** A system for tracking persons and other assets in a structure, having a mutli-function tracking tag and a network of fixed RF receivers forming a gateway array. The location of the person being tracked is calculated by a computer using an algorithm that weights each separate signal according to the probability of its accuracy, thus using data with the least error. A preferred algorithm is shown in Fig. 2.

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LOCATION AND TRACKING OF PEOPLE WITH COMBINED USE OF RF INFRASCTURE AND DEAD RECKONING MODULES

FIELD OF THE INVENTION

The present invention relates to a tracking system. More particularly, the present invention relates to an improved algorithm for use with a dead-reckoning module in each mobile tag and a fixed beacon to locate the mobile tag, and person using it, even when a fixed position beacon has moved for some reason.

BACKGROUND OF THE INVENTION

First responders such as fire fighters, police officers, and search and rescue teams are subject to numerous dangers. A significant contributor to these dangers is the potential of being lost or disoriented within a building that is filled with smoke and collapsed structures.

Radio Frequency (RF) based tracking systems rely on a combination of fixed beacons and mobile tags to track the movement of the tags, based on signal strength or time-of-flight measurements of specific RF signals. Near-continuous RF links with the beacons are necessary for the system to calculate timely location information. However, RF propagation variability may result in loss of path data for a mobile tag or tags. An alternative approach, which overcomes the RF link variability issue, employs a dead-reckoning module (DRM) in each mobile tag. The DRM can contain multiple sensors, such as altimeters, barometers, accelerometers, temperature sensors, and compass sensors, for example. The RF link is then used solely for data communications between the mobile tags and the base stations.

However, determining the absolute location of each mobile tag would require a known frame of reference within which the mobile tags are used. The cost of such a frame of reference would be prohibitive, needing a high density of beacons for RF tag tracking or adding GPS capability to the DRM. Moreover, both the RF and the DRM approaches have error sources which exhibit cumulative effects such as multi-path in the RF tags and sensor drift.

Movement, or failure, of receivers may degrade the accuracy of the position location information. Specifically, the use of RF tracking systems to monitor persons, such as first responders, may encounter a catastrophic event such as a building collapse, leading to the effective re-location of one or more of the receivers. In this case the

reported tag location will be corrupt due to the displacement of the receivers and subsequent apparent co-location of a tag near multiple receivers.

One of the problems with systems that calculate the location of an individual using a plurality of signals is that some signals may be less representative of the actual location than others. Prior art systems do use signal strength to determine location from multiple anchors.

It would be of advantage in the art if a system could be devised that would permit the use of an array of fixed beacon receivers that would maintain their utility even when moved due to outside influences such as damage to the place where the beacon receivers are fixed such that the calculations of signal strength could be weighted to favor those signals of maximum confidence.

Yet another advantage would be if a tracking tag could be developed that would allow integration of DRM data that is weighted to use signals that have maximum confidence factors.

Still another advantage would be if errors arising from multiple RF transmissions could be compensated for by weighting the respective signals.

Other advantages will appear hereinafter.

SUMMARY OF THE INVENTION

It has now been discovered that the above and other advantages of the present invention may be obtained in the following manner. Specifically, the present invention includes three basic components.

First, a beaconing sensor package is worn by an individual and a plurality of radio receivers are placed in an array in a specific area to be monitored, such as a building in which the individual has entered. A computer then integrates all the location information using an algorithm according to this invention, and then displays the relevant information on a user interface.

The algorithm of the present invention takes known data and solves for the unknown, that being the location of the individual first responder. This location is designated as (X_B, Y_B) where X and Y are coordinates representing a location. A plurality of RF anchors have known locations designated as (X_i, Y_i) where i = 1.....n. Signal strength of beacon's transmissions is represented by S_i where i = 1.....n. The location of each DRM is designated as X_{drm} Y_{drm} and the distance to signal strength function is $d_i \cong f(s_i)$ is approximately known with some error bounds. The present invention minimizes the squared error between the Euclidean distance for $(X_B\ Y_B)$ and $(X_i\ Y_i)$ and the distance estimated from the distance to signal strength function in addition to the squared error between $(X_B\ Y_B)$ and the DRM location prediction.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the invention, reference is hereby made to the drawings, in which:

FIGURE 1 is a schematic view of the present invention in which a person is inside an array of six beacon receivers;

FIGURE 2 is an equation of the preferred algorithm of the present invention;

FIGURE 3 is a graph illustrating the degradation of weights of DRM predictions; and

FIGURE 4 is a graph illustrating the degradation of weights if RF predictions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides for substantial improvements in a tracking system using an improved tag or module. As shown in Fig. 1, a first responder F is shown in an environment, such as inside a building. In this example, the first responder F is a firefighter engaged in a fire fighting operation in which he or she performs the appropriate work. In accordance with this invention, first responder F carries a beaconing sensor package that is in communication with an array of radio receivers 1, 2, 3, 4, 5 and 6, as shown in Fig. 1. The location of the first responder F is determined by processing the signals from the radio receivers 1-6 using the known coordinates of radio receivers 1-6 to locate the coordinates of the first responder F using the algorithm of this invention.

A more complete description of the environment of the first responder F in which the algorithm of the present invention may be used is described in a commonly owned U. S. Patent Application filed of even date herewith in the names of Philip J. Zumsteg and Steve D. Huseth entitled Multi-Function Tracking Tag With Robust Asset Tracking System, the disclosure of which is incorporated herein by reference in its entirety. In that system the first responder F carries a sending device that is received by a plurality of receivers that transmit that data to a monitor. This invention provides for a more accurate calculation of the location of the first responder F as set forth below.

The signal strength of the beacon of a particular radio receiver will be approximately proportional to the distance between the radio receiver and the beacon carried by the first responder F. By combining the signal strength of multiple radio receivers at known locations, such as receivers 1-6 in Fig. 1, the location of first responder F can be estimated. First responder F also carries a sensor package that includes sensors for determining building floor level, direction of travel, and rate of travel. An altimeter, magnitometer and accelerometer are provided to accomplish these measurements. This information can be combined with the signal strength information

from all the receiving radio receivers and sent to a computer using an algorithm to produce an estimated location of first responder F. When a first responder becomes lost or disabled, the command center will be able to quickly identify where the first responder F is located and send a rescue team or instruct first responder F how to move to a safe area.

One DRM is disclosed in U.S. Patent No. 5,583,776 to Levi et al., the disclosure of which is incorporated herein by reference in its entirety. This DRM is a microcomputer-assisted position finding device that integrates GPS data, dead reckoning sensors and digital maps and has a built-in RF transponder. The Levi et al. DRM provides ground speed/distance measurements and computer-aided position fixes. One such DRM device is available from Point Research Corporation, of Santa Ana California as the product Dead Reckoning Module (DRM) ®. The Dead Reckoning Module is a miniature, self-contained, electronic navigation unit that provides the user's position relative to an initialization point. The device includes a built in GPS receiver. A microprocessor performs dead reckoning calculations and includes a Kalman filter to combine the dead reckoning data with GPS data. The Kalman filter and other proprietary algorithms use GPS data to calibrate dead reckoning sensors for typical dead reckoning accuracy of 2 to 5 per cent of distance traveled from the last position fix, entirely without GPS. The evaluation kit includes test software and is supplied in a housing with belt clip, re-chargeable Li-Ion battery, and charger. These devices are intended for use by personnel on foot, and are not for use on vehicles.

At the command center or operations center, the signals from all the radio receivers 1-6 are fused using the algorithm of the present invention that employs a weighted multilateration technique to derive a new estimated position. The weighted multilateration algorithm has two significant innovations. Each term in the algorithm is weighted by the relative signal strength such that receivers receiving higher signal strength have greater weight than those receivers receiving lower signal strength. The purpose of this weighting based on signal strength because low signal strength signals

have greater variability and error. Also, a weight is applied to the estimated positions produced by the sensors based upon the expected confidence. The location determined by the sensors tend to drift over time and when the motion of the first responder becomes irregular, such as while climbing over obstacles, crawling, or jumping. Such irregularities are discernable from the sensor information and are used to reduce the weight of the sendor based estimated position in the location calculations.

The algorithm of the present invention takes known data and solves for the unknown, that being the location of the individual first responder F. This location is designated as (X_B, Y_B) where X and Y are coordinates representing a location. A plurality of RF Anchors have known locations designated as (X_i, Y_i) where i = 1.....n. Signal strength of beacons Tx is represented by S_i where i = 1.....n. The location of each DRM is designated as X_{drm} Y_{drm} and the distance to signal strength map is $d_i \cong f(s_i)$. Fig. 1 illustrates six RF Anchors, 1-6, having known coordinates X_{1-6}, Y_{1-6} as examples.

The present invention minimizes the squared error between the Euclidean distance and distance estimate and the error in DRM prediction. W_{rf} and W_{drm} are the relative weights between the RF prediction and the DRM prediction. It is known that W_{drm} is time varying and decreases as the DRM error drifts. W_i is a weighting factor proportional to S_i because d_i is more accurate for high values of s_i.

X_B, Y_B is found by solving the optimization problem which is shown in the drawings as Fig. 2, and in which the sum of the error value *J* based on signal strength is calculated to be the square root of the squares of the differences between values for all fixed X and Y coordinates and the coordinates of the responder. Both RF and DRM signals are calculated and used in this equation:

$$\text{Min } (X_B, Y_B)\ W_{rf} \sum_{i=1}^{n} w_i J^2_i + w_{drm} J_{drm}$$

where J_i and J_{drm} are defined above and in Fig. 2.

Figs. 3 and 4 illustrate the relative weights w_{drm} used in the algorithm as time progresses. In Fig. 3, the weight given to the DRM data decreases with time. In Fig. 4,

the weight given to the RF data decreases over distance. In both cases, each RF signal increases with increased signal strength and provides the weights for use in Fig. 2.

Solving the algorithm by a computer produces a much improved and more accurate representation of the location of the first responder F. That location is constantly updated as the receivers continue to send data to the computer, until the first responder F has reached a safe location or been found.

The number of RF anchors will be determined by the size of the facility, the expected danger for first responders and by other factors. The RF anchors can be located in the facility, and others may be positioned on mobile or stationary platforms outside the facility, including one or more on the command vehicle, if one is used.

The first responder is shown in this description as a firefighter as an example of a person who might use the present invention, but any person in any environment where position and safety is monitored at a remote location is part of this invention. Other persons by way of example and not as a limitation are police, military, national guard, EMT personnel and other medically trained persons, and the like are intended users of the present invention.

While particular embodiments of the present invention have been illustrated and described, it is not intended to limit the invention, except as defined by the following claims.

CLAIMS

1. A system for tracking persons and other assets in a structure, comprising:

a multi-function tracking tag for transmitting a RF beacon signal and a dead reckoning sensor, said RF beacon including data from said dead reckoning sensor;

a network of RF transceivers of known location forming a wireless array for receiving signals from said multi-function tracking tag and transmitting said signals; and

a computer gateway for receiving said transmitted signals from said network, said computer being adapted to determine the location of said tag from said transmitted signals using an algorithm that weights the strength of the RF signal and position data of the dead reckoning sensor.

2. The system of claim 1, wherein said algorithm is a weighted, multilateration algorithm.

3. The system of claim 2, wherein said algorithm is the algorithm of Fig. 2.

4. The system of claim 1, wherein said dead reckoning sensor includes at least an altimeter, a magnitometer and an accelerometer.

5. The system of claim 4, wherein said dead reckoning senor combines readings from said sensors with an initial starting position to produce a new estimated position.

6. The system of claim 1, wherein said dead reckoning sensor transmits uncombined data for processing in said computer gateway.

7. The system of claim 1, wherein said dead reckoning sensor transmits a fully integrated location estimate, said estimate being merged into said algorithm by said computer gateway.

8. The system of claim 1, wherein said multi-function tracking tag includes a processor for determining said position with said algorithm using said tag's dead reckoning data and RF signal strength.

9. The system of claim 1, which includes a plurality of tags each having dead reckoning data and RF signal strength determination for use in said algorithm.

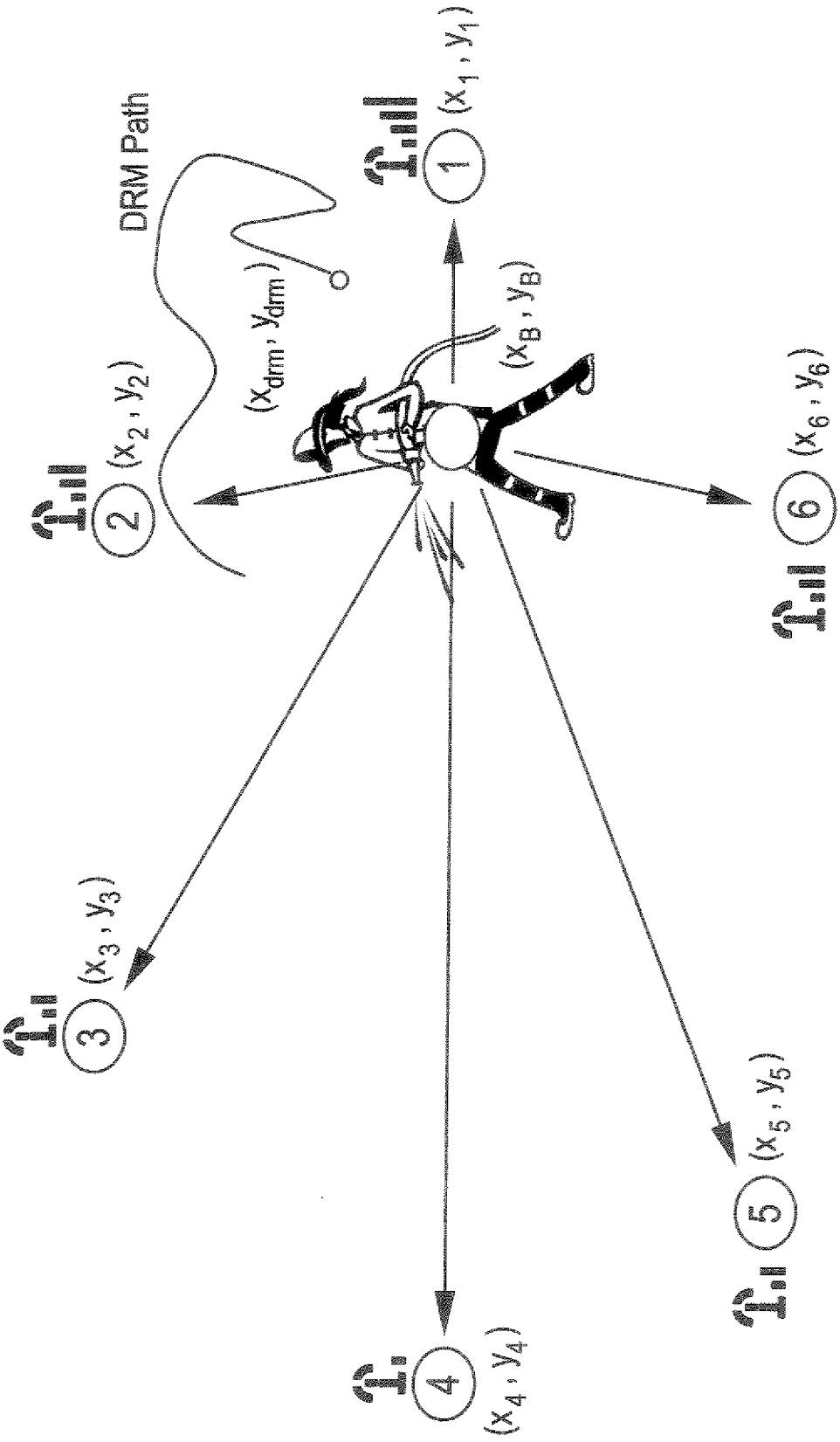


FIG. 1

$$\min_{x_B, y_B} w_{rf} \sum_{i=1}^{n} w_i J_i^2 + w_{drm} J_{drm}$$

$$J_i = \sqrt{(X_i - X_B)^2 + (Y_i - Y_B)^2} - d_i$$

$$J_{drm} = (X_{drm} - X_B)^2 + (Y_{drm} - Y_B)^2$$

FIG. 2

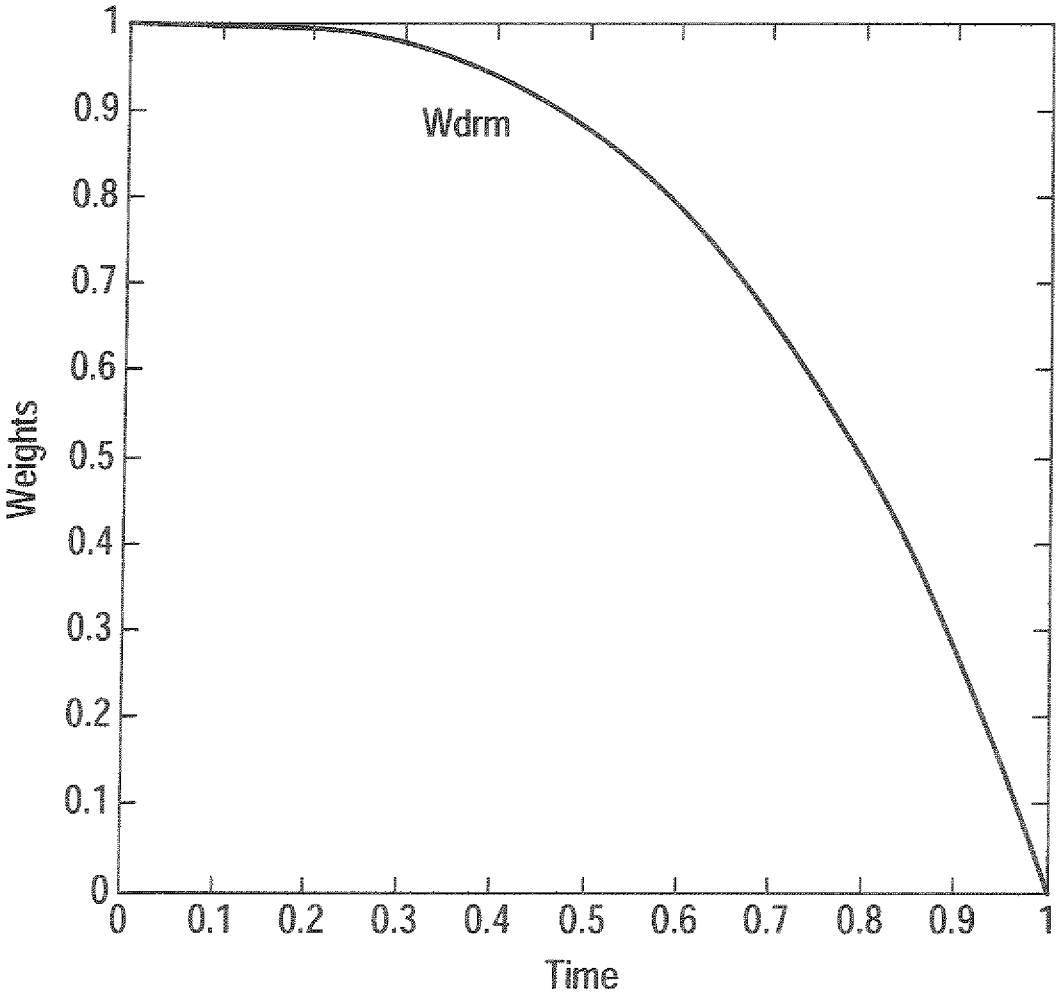


FIG. 3

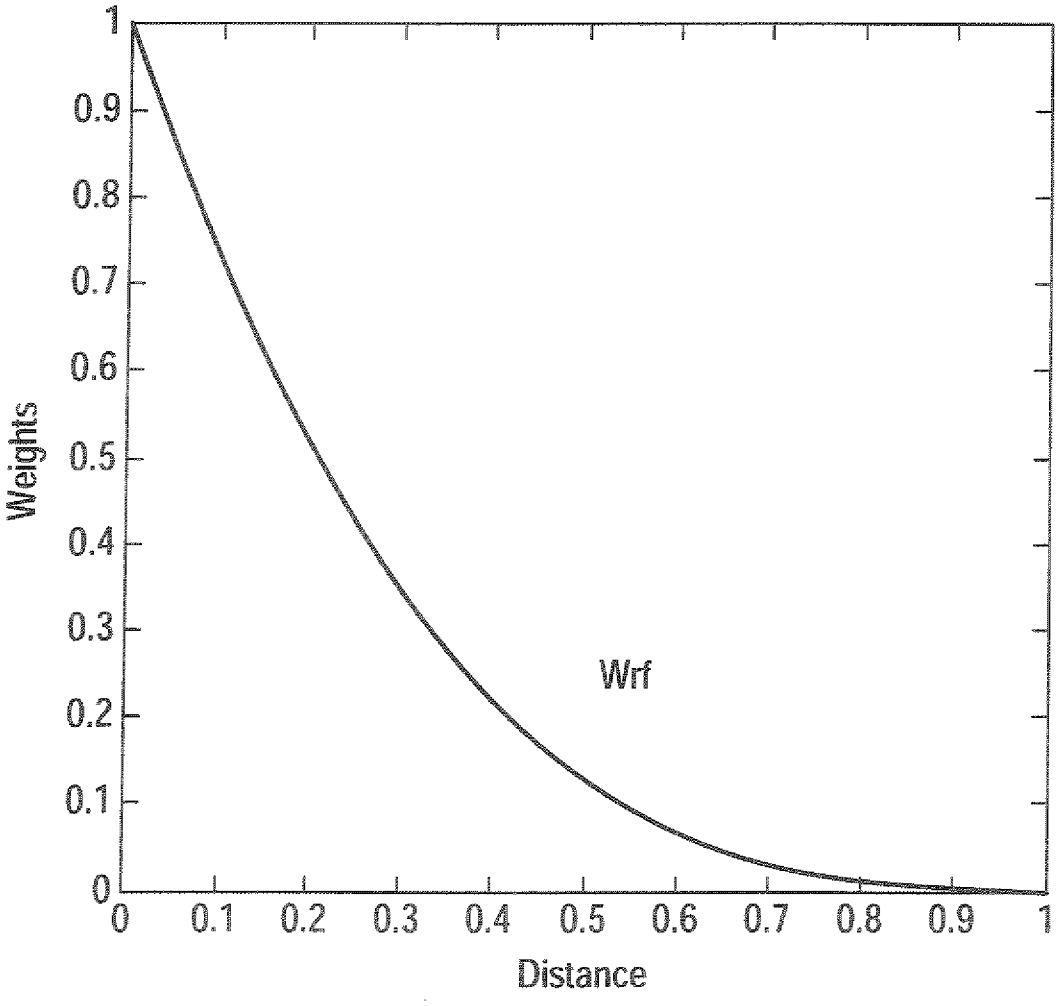


FIG. 4