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The Hunter: Tracking Randomly Moving WBAN Targets

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***Abstract*—Wireless Sensor Networks are often large networks comprised of nodes that monitor through sensors interesting targets. Wireless Body Area Networks are always small networks that often monitor the health of a single human subject. Although WBANs are limited in size, the information they monitor is urgent and important. Information from a WBAN producer may be transmitted over a WSN to the intended consumer.**

The above use case usually involves a smaller number of WSN nodes compared to a larger number of potential WBAN targets or even only one of each kind. In this context, a mobile WSN node should continuously "hunt" a mobile WBAN target in order to ensure uninterrupted monitoring.

Thus, a Hunter-Prey model is introduced in the paper and evaluated for different mobility patterns and parameters.

***Index Terms*—WSN, WBAN, BSN, robot, smart agent, tracking, RSS**

I. INTRODUCTION

WSNs are usually networks of spatially distributed autonomous nodes that monitor various physical conditions through appropriate sensors and exchange data wirelessly. Additionally, WSNs are dynamic in nature, due to planned and unplanned changes in their composition or structure. Wireless Body Area Networks (WBANs) or Body Sensor Networks (BSNs) differ compared to most WSNs. Unlike the others, WBANs are networks of nodes that are either embedded in or attached to the body of the user, or worn by or carried by the user. Also, WBANs are relatively static, because they are comprised of a limited number of nodes in fixed positions. Their most prominent application is health monitoring [1], [2].

There are cases where the relative scarcity of available nodes to the abundance of mobile targets imposes certain mobility and intelligence demands on the nodes. Such cases include the case of a soldier in the theatre of operations, or an athlete on the track or court, or a patient in a hospital or clinic, etc. In fact, there has always been a need to monitor the status of a patient, especially after a surgical operation and during the subsequent recuperation period. More so, concerns are increasing as the world population grows older. Additionally, a shift from re-active management of illness to the pro-active management of health has been observed even among those members of the population who pose lesser health risks [3], [4]. Ideally, health monitoring would be constant, synchronous and unobtrusive. Such monitoring would facilitate personalised health care, prompt intervention and increased comfort. An extreme example would be that of a post-operational patient. Such a patient could wander in the hospital premises and would not be grounded on their bed or constrained in their room, whilst being monitored. Usually, this is achieved with a gateway device that relays the information like a mobile phone. Potentially, this could also be achieved by a combination of a WBAN covering a patient and of a WSN covering the hospital. The relative advantages of the latter to the former solution are it is *a*) private and not publicly accessible to third parties, *b*) autonomous and not dependent on extant infrastructure, and *c*) flexible and adaptable to many scenarios.

In order to cover a case similar to the aforementioned, a model is proposed which consists of *a*) the Base, which is the base station, where all the information that originates from a target and is transferred from a node is collected; *b*) the Hunter, which is a robot, that is a mobile node, which includes both sensors and actuators; *c*) the Prey, which is a source of sensory information, that is a mobile target of interest, which is energy constrained. The Hunter is capable of long range communication with the Base, but follows the Prey, because the Prey is only capable of short range communication. The Hunter can *a*) detect possible targets in the vicinity; *b*) select the most interesting target; and *c*) track the selected target, that is to locate and follow the target. In this model, the Prey is a WBAN, and the Prey, the Hunter and the Base combined a WSN.

The main contribution of this work is a model where the information originating in a personal area WSN, like a WBAN, is transmitted over a wide area WSN without needlessly expending resources, like adding hardware (e.g. sensors or transceivers) or increasing energy consumption (e.g. by boosting transceiver power output) on the WBAN. Obviously, both aforementioned resources are in sort supply on a small, light and energy constrained WBAN. Furthermore, such a model would offer increased safety, since a target could be followed constantly and reliably, but also discreetly and unobtrusively.

The rest of this paper is organised as follows: section II provides the problem description, section III outlines past relevant work, section IV describes the proposed model, exposes the necessary work assumptions and describes the simulation parameters, section V presents the simulation results, and section VI adds a few thoughts and summarizes this paper.

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II. Problem Statement

The main aspect of this research is the ability of a single node with a single sensor to follow a target irrespective of the type of sensor integrated in said target (e.g. acoustical, optical, electromagnetic) in order to ensure uninterrupted communication between the target and the base station. Following presupposes locating and locating implies some form of triangulating.

Moreover, the need of electromagnetic means of wireless communication between node and target implies, that at least one facility exists on the node that may function as a sensor: a electromagnetic receiver, that may function as a signal strength sensor. This further implies that any other sensor on the node would be superfluous and could be avoided.

Preferably, the node has to surmise where the target has moved, and if it is still moving, then what is its speed and direction, whenever the node detects target movement. In other words, the node should probably be able to move rapidly and randomly in the small area around its initial position and take multiple measurements in rapid succession of the strength of the signal transmitted from the target and received from the node (Received Signal Strength - RSS) within that area, in order to perform triangulation, either periodically, that is at regular intervals, or reactively, that is whenever it detects an alteration in the strength of signal from the target.

Naturally, a plethora of questions arise concerning triangulation. For example, whether triangulation is even possible with a single tracker. It appears that it may be possible, but only if some conditions are met. Namely, that the node ought to be more mobile than the target in order that the node is capable of keeping up with the target's movement and taking multiple spatially distant and temporally close measurements. Also, that the relevant criterion for triangulation is always available, that the necessary triangulation calculations are fast and conclusive, etc. An additional question is whether intermittent target movement affects detection. Certainly, movement affects detection, and thus the node should be able to take multiple signal strength readings and calculate the position, speed, and bearing of the target near synchronously.

Also, additional questions arise concerning following. For example, whether the node can keep up with a potentially randomly moving target. Again, this seems possible provided that certain conditions are met. Namely, that the node is more mobile than the target.

III. Related Work

Generally, location detection may be performed through three main techniques, that is through triangulation, proximity or scene analysis, which may be used either independently or jointly. Triangulation itself involves lateration and angulation, which use distance and length measurements, and bearing and angle measurements respectively [5].

In detail, lateration requires three distance measurements, each between the point of interest and three other non co-linear points. Measurements may be performed directly by physically traversing the distance between two points or indirectly by correlating attenuation and distance of a transmission. On the other hand, angulation is similar to lateration with the exception that it also uses angles instead of only lengths. Angulation requires two angle measurements for a two dimensional space and three angles for a three dimensional space. Irrespective of the method used, location may be physical or symbolic, relative or absolute, whereas the accuracy and the scale largely depend on the the means to perform the measurements and their precision.

Specifically for WSNs, some systems use the received signal strength (RSS). One such system is RADAR, which was developed by Microsoft [6]. It uses triangulation techniques and IEEE 802.11 wireless networking technologies. It measures at the base stations the signal strength and the signal-to-noise ratio of the transmissions of the mobile nodes and then it uses these measurements to calculate the location of these nodes.

Other methods, instead of relying on RSS, rely on Time of Arrival (ToA), Time Difference of Arrival (TDoA), Phase of Arrival (PoA), Direction of Arrival (DoA), or Angle of Arrival (AoA) of the received signal [7], while some others combine several [8], [9]. Unfortunately, these methods presuppose the availability of lots of processing power or a very precise time source (e.g. ToA, TDoa, PoA), or special receiver with unidirectional antenna (e.g. DoA, AoA), with the former three being less of a issue, due to the recent improvements in microcontroller performance, but the latter two posing a valid concern since most widely and readily available wireless products, like those based on IEEE 802.11 (WiFi) and IEEE 802.15.4 (XBee) technologies usually use omnidirectional antennas. In fact, it appears that this is the main reason RSS techniques are preferred over others [10].

Even so, tracking of a mobile target, which is active (i.e. transmitting) but otherwise uncooperative (i.e. not providing any position information), by a mobile node, which is alone and not part of a larger network of nodes, appears to be relatively uncharted territory.

Concerning WBANs, communication may be categorised as either intra-body or extra-body, depending on whether it occurs within the WBAN, that is among the sensors and actuators that comprise the WBAN, or between the WBAN and another network. The former type of communication is inherent in a WBAN, whereas the latter is not. As is often the case with WBANs, extra-body communication is is facilitated by a designated gateway device capable of long range communication [2], [11]. Usually, that device is a mobile phone that is carried by the user, or a wireless modem that is part of equipment of an ambulance, etc.

IV. Proposed Model

A. Simulation Parameters and Simulation Environment

Although the proposed system simulated is modeled after possible real systems, it is otherwise agnostic to the underlying technology. For example, the communication properties were modeled after popular technologies, like either IEEE 802.11 (WiFi) or IEEE 802.15.4 (XBee) for Base-Hunter communication, and either IEEE 802.15.1 (Bluetooth and Bluetooth

Low Energy) or IEEE 802.15.6 (IEEE WBAN) for Hunter-Prey communication. Thus, the acceptable range for the former was set to $100m$ and for the latter to $10m$. But any comparable technology could be used.

Also, the physical properties of a possible real system were taken into account. For example, the work envelope of the system was set to $900m^2$ ($30m \times 30m$) and the default speed of the Prey to a maximum of and reasonable $1m/s$ ($3.6km/h$).

Additionally, all algorithms were tested for one thousand cycles. This number was finally chosen, after initial experimentation with smaller numbers, because the results seemed to stabilise at that number.

The simulation environment chosen was Processing [12], because it aims to provide visual context and feedback to programmers. In more detail, Processing is both a programming language and an integrated development environment and it is based on and built around Java.

B. Work Assumptions

A few basic assumptions had to be made in order to simplify the problem and focus on specific parts of a solution. Namely, that the target periodically broadcasts its sensorial information, which decouples information monitoring, which happens on the target, from information collection, which takes place on the node. Another assumption is that there is a single node and single target, which further simplifies the problem by merging the aforementioned Detect and Select functionalities of the node. That both target and node move within a flat, two dimensional, unobstructed space, which removes the problem of obstacle avoidance and simplifies triangulation by limiting it to a two dimensional problem. And that the base is immobile, while both the node and target are mobile, which reduces the degrees of freedom of the system to only four. Also, the node-to-target range is small and the base-to-node range is big, which pushes tracking exclusively to the node. That the target may move randomly, but it also moves slowly, and thus the node is always able to catch up with the target.

C. Tracking Algorithms and Movement Algorithms

For this paper, several algorithms were implemented and evaluated. Namely, three different random movement algorithms were implemented on the Prey, whereas the simplest tracking algorithm was implemented on the Hunter.

The first of the three algorithms implemented for Prey movement (alg. 1) was Random Movement or Random Walk [13], which is comparable to Brownian Motion [14]. Plainly, the Prey would simply move to random new location within a certain range from its old location.

Algorithm 1 Random Movement algorithm

```
while true do
    $newRandomLocation \leftarrow randomLocation(current)$
    $fleeByPreyStep(newRandomLocation)$
end while
```

The next algorithm (alg. 2) implemented was a Probabilistic Walk with Branching or Branching Random Walk algorithm [15]. In more detail, the Prey movement is biased for a number of rounds each time in either direction on both axes. For example, the Prey would move to the 'left' for 5 rounds, before turning to the 'right', and it would move to the 'bottom' for 7 rounds, before turning to the 'top'.

Algorithm 2 Probabilistic Walk algorithm

```
$biasX \leftarrow random(top, bottom)$
$biasY \leftarrow random(left, right)$
$biasXRounds \leftarrow random()$
$biasYRounds \leftarrow random()$
$counter \leftarrow 1$
while true do
    if $(counter \% biasXRounds) = 0$ then
        $biasX \leftarrow reverse(biasX)$
    end if
    if $(counter \% biasYRounds) = 0$ then
        $biasY \leftarrow reverse(biasY)$
    end if
    $newRandomLocation \leftarrow randomLocation(currentLocation, biasX, biasY)$
    $fleeByPreyStep(newRandomLocation)$
    $counter \leftarrow counter + 1$
end while
```

The last algorithm (alg. 3) implemented was one with Random Waypoints movement [16], where a new way point appears at a random location after a number of rounds and the Prey would move towards it.

Algorithm 3 Random Waypoints algorithm

```
$wayPointRounds \leftarrow random()$
$wayPoint \leftarrow randomLocation()$
$counter \leftarrow 1$
while true do
    if $(counter \% wayPointRounds) = 0$ then
        $wayPoint \leftarrow randomLocation()$
    end if
    $fleeByPreyStep(wayPoint)$
    $counter \leftarrow counter + 1$
end while
```

As mentioned, the Hunter track algorithm (alg. 4) is as simple as possible. According to it, the Hunter makes three distance measurements from the Prey (converting from the logarithmic RSSI to the corresponding linear distance), then it triangulates the current location of the Prey (with some error injected externally to simulate real world scenario), and follows the Prey (moving for a distance less or equal to the maximum allowed from its current position).

It must be noted, that in the cases of the Hunter and Prey the distance either can cover per cycle (i.e. their speed) is limited to a "Hunter Step" and a "Prey Step" respectively.

V. RESULTS

Although some of the results confirmed preconceived notions, others were more revealing. To elaborate, fig. 1 shows

Algorithm 4 Track algorithm

```
while true do
    $counter \leftarrow 1$
    repeat
        $distanceFromPrey[counter] \leftarrow convertToDistance(PreyRSSI)$
        $randomLocationNearby \leftarrow randomLocation(currentLocation)$
        $move(randomLocationNearby)$
        $counter \leftarrow counter + 1$
    until $counter = 3$
    $locationOfPrey \leftarrow triangulate(distanceFromPrey[])$
    $followByHunterStep(locationOfPrey)$
end while
```

how the average distance between Hunter and Prey is affected by the distance estimation error, that is how even small inaccuracies in distance measurements ($<< 1\%$) cause more pronounced errors in the triangulation and in turn prevent the Hunter from closely following the Prey.

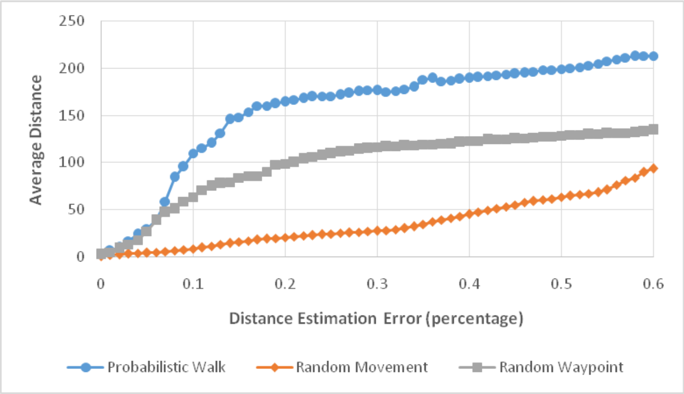

Fig. 1. Average distance between Hunter and Prey versus distance estimation error for different Prey mobility models.

Correspondingly, fig. 2 demonstrates how the ability of the Hunter to remain in contact the Prey is greatly impaired, even when the error in distance estimation is surprisingly low for reasons similar to the aforementioned. Eventually, the Prey drifts away from the Hunter and contact is lost.

Additionally, fig. 3 exhibits that the average distance between Hunter and Prey also increases with the mobility of the Prey. Indeed, once the Prey Step becomes greater then the Hunter Step, the Hunter becomes unable to successfully follow the Prey. Here it must be noted that the unit of length in the figures below is equal to $1/20m$ and the Hunter Step is fixed to 10 units.

Following up to that point, fig. 4 shows that the Hunter cannot remain in contact the Prey for long after the Prey Step increases to a value comparable to the Hunter Step in Probabilistic Walk and Random Waypoint models.

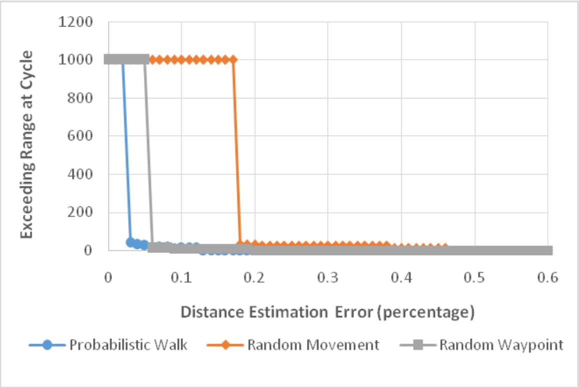

Fig. 2. Cycle when Prey's range is exceeded versus distance estimation error for different Prey mobility models.

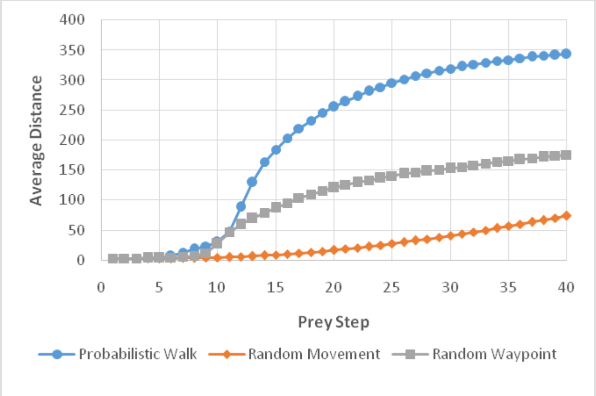

Fig. 3. Average distance between Hunter and Prey versus Prey step size for different Prey mobility models.

Also, fig. 5 presents how often the Prey remains within the reach of the Hunter for different values of error in the distance calculations. It appears that the error affects the reach linearly for the Random Movement model, but exponentially for the Probabilistic Walk and Random Waypoint models.

Finally, fig. 6 reveals that if the Prey Step is equal to or bigger than the Hunter Step, then the Hunter is unable to keep up with the Prey with the percentage of success dropping sharply when the Prey Step exceeds the Hunter Step.

Generally, the ability of the Hunter to track the Prey is inversely correlated to the speed of the Prey, the determination of the movement of the Prey and the error in the measurement of distance between the Hunter and the Prey. Specifically, once the speed of the Prey becomes greater then the speed of the Hunter, tracking becomes near impossible. Also, if the Prey moves intently, either in a specific direction or towards a specific position, the Hunter has a problem following it. Furthermore, even miniscule errors in distance measurements have an adverse and amplified effect on triangulation and hence on localisation.

VI. CONCLUSION

Based on the simulation results, one may conclude that indeed a mobile node may track a mobile target successfully

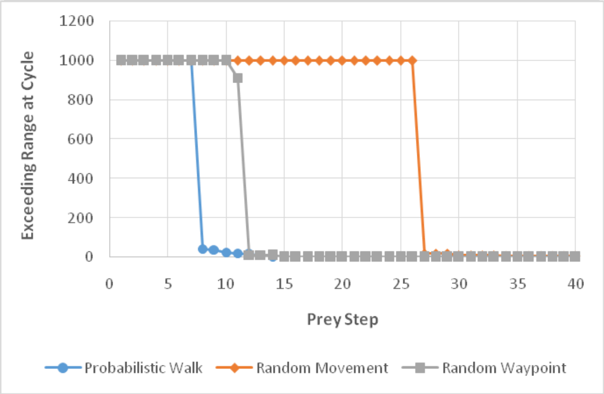

Fig. 4. Cycle when Prey's range is exceeded versus Prey step size for different Prey mobility models.

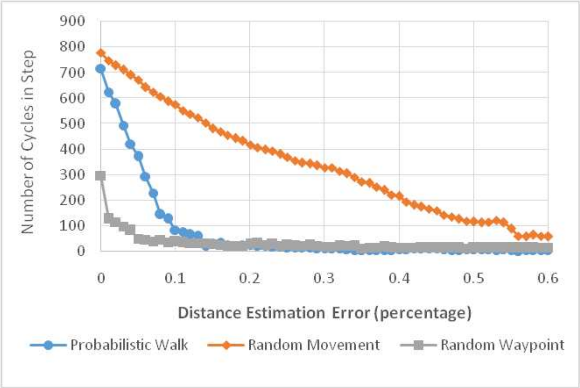

Fig. 5. Number of cycles Prey is in Hunter's step versus distance estimation error for different Prey mobility models.

provided some conditions are met, and thus a patient featuring a WBAN may be monitored by a single mobile WSN node within hospital premises with some limitations.

Three different movement patterns were implemented from the highly uncertain Random Movement to the modestly deliberate Waypoint Movement. It seems that the less purposeful the target the less it deviated from the initial position, and thus the node was able to track it successfully. Even so, if the target is faster than the node, then the chances of the node tracking the target decrease considerably. Also, performance is negatively affected by the error in target location estimation.

Future work may include other algorithms for each operation the Prey performs and even more for each the Hunter performs. For instance, apart from the simple algorithm shown here, there are others based on simple feedback mechanisms, like a Control System with closed-loop feedback, and still others based on prediction techniques, like Learning Automata, Markov Chains, Intra- and Extra-polation and even Neural Networks.

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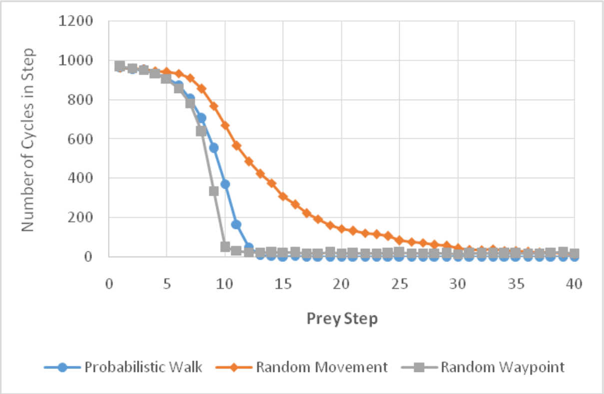

Fig. 6. Number of cycles Prey is in Hunter's step versus Prey step size for different Prey mobility models.

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