

An Investigation of Delay-tolerant Sensor Networks: Towards the Use of Mobile Robots in Node Localization

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Abstract--- In this study, a novel scheme is presented. The scheme targets delay-tolerant network (DTN) node localization. Indeed, sensor devices in DTN are designed in the form of network clusters, hence mutual interconnections. To collect data from these network clusters, certain mobile robots could be used. In this study's scheme, the objective is to employ the robot to implement the location estimation process for sensor nodes with which it interacts relative to the radio messages' signal strengths, having received the signals from the sensor nodes. The implication is that the central purpose of the study lies in the elimination of the static sensor nodes' processing constraints. Imperative to highlight is that the study's mathematical contribution lies in the utilization of the REKF-based state estimator to analyze the localization problem. Deviating from Kalman Filter, it is worth noting that REKF exhibits computational efficiency and robustness. Indeed, the localization scheme is implemented on a hybrid network test bed. Findings demonstrate that the proposed design is accurate relative to the node localization process, especially within large indoor settings, as well as 1m.

Keywords--- Mobility, Mobile Robot, Robust Extended Kalman Filter, Delay-tolerant Sensor Networks, Localization.

I. INTRODUCTION

IN the recent past, sensor network research has increased dramatically [1, 2]. In particular, the wide range of possible applications has motivated the research efforts, including the condition-based maintenance of aircrafts and environmental monitoring [3, 4]. Imperatively, the sensor networks involve extremely limited processing capability, memory, and end-node power, and are at large scale [5]. Indeed, some environmental monitoring applications do not necessarily call for the use of uniformly distributed and fully connected sensor networks [6]. Also, these applications do not necessarily call for the use of real-time sensor information [7, 8]. For scientific analyses, the majority rely on sensor data that has been obtained for a significant period, examples being long-term coastline monitoring and the monitoring of cane toads [9, 10].

In relation to the examples of applications mentioned above, many studies affirm that the DTN concept gains usage. In particular, the role of DTN lies in the monitoring of environments for a significant period, especially in environments with non-interactive sensor data traffic [8, 10]. In such environments, the DTN sensors are utilized by ensuring that they are scattered randomly before being organized to established clusters that are likely to be separated from each other, should the need arise. It is also

notable that cluster heads are found on individual clusters and it is at these cluster heads that there is typical aggregation of sensor information [4]. Hence, the cluster heads are equipped with information and play the role of data command to the rest of the external world [5].

In relation to the case of wireless mobile robots, their role lies in roaming around the target networks while collecting relevant data gained from the cluster heads. Also, the robots reconfigure or reprogram the sensors dynamically [3]. Specific examples of DTNs that have gained increasing application include Data Mules, Zebranet, and Sammi [10]. In this study, the central purpose is to propose a technique through which, given a DTN, node localization could be performed by one or more mobile robots. The specific objective of the investigation lies in the development of a novel RKEF-based state estimation model for DTN-led node localization. Lastly, the study's goal lies in the implementation and validation of the proposed scheme relative to a novel hybrid sensor network.

II. MATERIALS AND METHODS

To address the problem of node localization relative to a mobile robot's RSSI measurements, the modeling assumes that the localization is in the form of an online application characterized by a non-linear dynamic design.

The figure below illustrates the RKEF model that will be used in the experimental implementation.

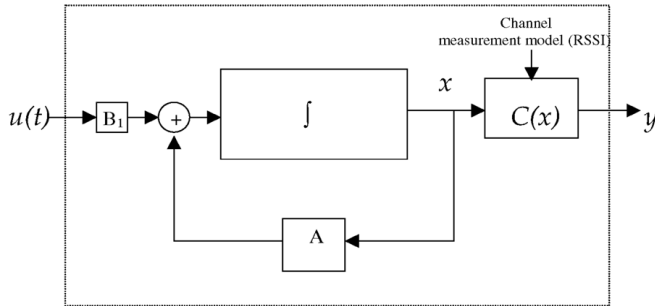


Figure 1 - An Illustration of the RKEF Model to be used in Model Implementation

Sources: Bahl and Padmanabhan (2000)

Indeed, the receiver's forward link received signal strength indication (RSSI) is used to observe distance between communicating entities within the chosen wireless network. Should there be multiple transmitters, the transmitter or source identifier will be used to determine measurement that comes from each transmitter precisely within the data packet. The modeling of RSSI in this study, which is found at the mobile robot and measured in decibels, is determined in terms of two effects. The effects include shadow fading and path loss. It is also worth noting that the experimental set-up constitutes simulations aimed at discerning the degree to which RKEF might perform in a given sensor network, a procedure achieved via the simulation of a mobile robot with which a radio receiver is equipped while ensuring that it moves in a given sensor coverage area.

The study's central assumption is that the network is capable of determining the position and acceleration of the mobile robot through accelerator readings, as well as GPS. Another assumption is that the network is not capable of gaining information about the sensors. Finally, the accuracy and precision of the proposed framework is evaluated by simulating two scenarios. These scenarios include small sensors and large sensors.

III. RESULTS AND DISCUSSION

One of the specific points under examination involved computational efficiency. Indeed, the computation time for RKEF was measured in relation to 10 sensors, with RSSI samples considered. Specific cases that were used in this implementation included Java implementation with Open-Wonka, Matlab implementation on a machine at Pentium IV 3GHz, and Java implementation on a machine with Pentium IV 3GHz. The table below shows the computation time in milliseconds.

Table 1 - Computation Efficiency Results

Number of Samples	Pentium-IV (Java) (seconds)	Pentium-IV (MATLAB) (seconds)	STARGATE (Java) (seconds)
90	-	-	115
2000	4	70	-
8000	15	27	-
16000	27	56	-

From the table, there was no statistically significant difference between the performance of Java and Matlab running on a Pentium IV 3GHz machine. On the other hand, there was significant degradation in the performance of a Stargate with an increase in the sample number. Hence, it was evident that the Stargate exhibits very limited memory, yielding inefficiency in Open-Wonka's garbage collector.

In the proposed design, another parameter that was evaluated concerned estimation accuracy. Particularly, four sensors were used. The choice of four sensors was necessitated by affirmations that when a smaller number of sensors are used, there is likely to be a clearer visualization of estimation convergence. From the results, with 1m being the approximate error, the outcomes were very close to actual positions. The figure below summarizes the study's findings that were obtained relative to the examination and evaluation of the parameter of estimation accuracy.

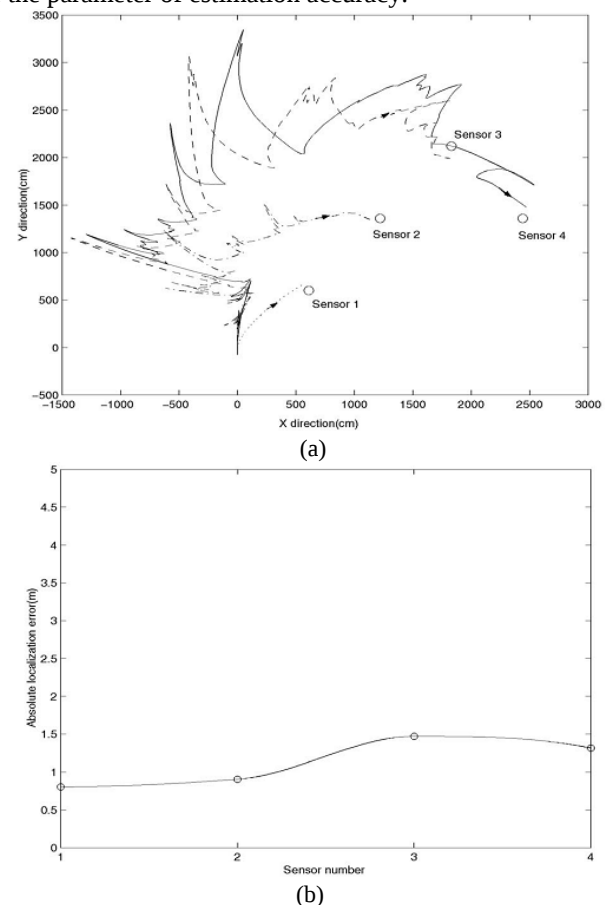


Figure 2 - Summary of the Results about Model Estimation Accuracy

In Figure 2 above, the left section illustrates sensor localization while the second figure demonstrates the real system's localization error. Based on the results of this experimental evaluation, this study inferred that it is essential to determine the right parameters regarding weighting matrices. Also, the results demonstrate that when DTN-based mobile robots are used, with sensor localization implemented, path profiles or topological maps could be created. Upon optimizing these maps, the mobile robot-collected data can follow the resultant path to ensure that the shortest possible

time is used to collect data. Also, the optimization would aid in meeting the power and storage requirements of the designed system. It is also notable that this study's findings suggest that mobile robots are worth utilizing to act as relays between a network's disconnected portions, hence yielding a relay network. Lastly, it is evident that a mobile robot's trajectory could be recalculated dynamically to ensure that it slows down when there is a need to download much data.

IV. CONCLUSION

In summary, this study has offered a scheme through which node localization could be achieved via the use of mobile robots. The target context of the experimental set up has been the case of a DTN network. The objective has been to employ the robot to implement the location estimation process for sensor nodes with which it interacts relative to the radio messages' signal strengths, having received the signals from the sensor nodes. The implication is that the central purpose of the study lies in the elimination of the static sensor nodes' processing constraints. Imperative to highlight is that the study's mathematical contribution lies in the utilization of the REKF-based state estimator to analyze the localization problem. Deviating from Kalman Filter, it is worth noting that REKF exhibits computational efficiency and robustness. Indeed, the localization scheme is implemented on a hybrid network test bed. Findings demonstrate that the proposed design is accurate relative to the node localization process, especially within large indoor settings, as well as 1m.

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