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学位論文の要旨

Wireless Sensor Network (WNS) is a domain in ubiquitous computing technologies that can incorporate the *sensor nodes* (SNs) with outside worlds. In WSN, localization is a process that deals with how to use information from SNs to determine the unknown locations of SNs. Localization methods that have the capability to perform high accuracy of localization in a low cost environment with easy deployment has attracted a great deal of attention.

Proximity- based localization is a method that can deal with solutions of localization in easy deployment. In proximity-based localization, the information about connections between neighboring SNs has been exploited without measuring exact distance between SNs. Proximity-based localization that utilized *Received-Signal-Strength* (RSS) has become popular because of its inexpensive solution to the problems of localization. RSS provides useful information that is distantly related in addition to indicating connectivity information between neighboring nodes. The majority of the proximity-based localization assume the presence of anchors that know their exact locations in advance. Anchors that are located in the communication range of SNs can be used as reference locations to determine the location of SNs, called as *estimates position* (EP), based from the connectivity information between neighboring SNs and anchors.

The purpose of this PhD thesis is to propose the solution of mobile localization that employs the proximities information of anchors in RSS-based localization. In most proximity-based localization, EP is determined by calculating the average location of anchors that are located in the communication range of an SN. We consider the errors of radio propagation in dynamic environment could affect whether an anchor should be used or not in calculating an EP. Although the anchors are always assumed to be precisely deployed at their predetermined positions, we consider this assumption is not realistic. It is difficult to maintain such positions in a realenvironment without providing a particular monitoring system for eachanchor to assure their locations. Many of the previous researches have performed the good performance of their localization method, however, most of researches did not address the problem of how to assure the reliability of anchor selection in estimating an EP. In this PhD thesis, we select the reliable anchors for the localization, instead of using all possible anchors. Reliable anchors are the anchors that are located in the communication sphere of an SN which have less variety of their distances to the center of the sphere.

We define the problem of determining the reliable anchors by comparing the radio propagation in a noise-free environment and noisy environment. In a noise-free environment, radio propagation is ideal, an SN can communicate with anchors located in a perfect sphere centered on an SN with a radius that is equal to its standard interrogation. Average of anchors might be close to the center of a perfect sphere of the communication area which denotes to the true position of SN. On the other hand, in a noisy environment, the radius of the sphere (which is imperfect) are varied significantly, which contribute to the inaccuracy of average-based calculation of EP. The selection of reliable anchors can be determined by assuring the average of selected positions of anchors to be closer to the center of communication sphere. However, location of center of communication sphere is unknown.

The objective of this PhD thesis is to select the reliable anchors in noisy environments by using *indicators point* (IP) as a metric to measure whether the EP is located close to the center of communication sphere or not. The closer EP to IP, the higher reliability of selected anchors. We select the anchors based on IP in two types of methods, a geometric- based anchor selection method and non-geometric-based anchor selection method. The localization that used a geometric-based anchor selection method can provide a capability to indicate whether EP is from a reliable selection of anchors or not by using geometric shape of anchor sequences. The drawback of this method is that it is ineffective in determining the selection of anchor sequences in the asymmetric geometric shape of anchor selection. The non-geometric- based anchor selection method can solve this problem by determining the selection of anchors based on individual anchor instead of anchor sequences. The use of individual anchor instead of anchor sequences can perform the selection of anchors effectively in asymmetric geometric shape of anchor selection.

In the geometric-based anchor selection method, we consider two phases of localization, selection phase and estimation phase. In selection phase, IP is used together with *reference point* (RP) which is derived from the average position of three anchors that have largest RSS. We select the anchor sequences that have small distance between RP and IP iteratively based on the genetic algorithm approach. In the estimation phase, the RSS measurement of selected anchors is converted into distance by using fuzzy logic approach to determine an EP. The major contribution of this method is to determine the reliability of anchor selection by comparing the distances of both EP and IP to RP. As for the results of simulation experiment, we demonstrated that we are capable to distinguish 89% of EPs that are determined from reliable anchors which have improved their meanlocalization error for about 53% compared to the EPs determined from all anchors.

In the non-geometric-based anchor selection method, the selection phase and estimation phase are performed repeatedly in improving an IP approaches to the true location of SN. We use the multiple anchors selections which has its own EP respectively. The concentration of multiple EPs gives us indication about the true location of an SN. The improvement of IP relies upon the concentration of EPs. The major contribution of this method is to provide the ability for SN to determine its location by using anchors selectively, although in the asymmetric geometric shape of anchors selection. As for the results of simulation experiment, we have demonstrated 80% of SNs have improved their IPs below 2m of distance between IPs and true position. The results of the experiments in this PhD thesis indicate that ourproposed method on incorporating reliable anchors in the proximity-based localization can improve the localization accuracy. This method can integrate with other mobile localization that used anchors as RP to increase the efficiency of using anchors in the localization of SNs.

論文審査の結果の要旨

近年，センサーを具備したセンサーノードが注目を浴びている．そのセンサーノードの位置が分からないとアプリケーションが制限されてくる. GPS の設置はセンサーノード位置を特定する一つの手段だが，屋内で利用できない，消費電力が大きい等の問題がある.

本研究はセンサーノードの無線通信の受信信号強度（RSS）を利用して，センサーノードの位置を推定する近接性方式による位置推定手法を提案している．これまでの位置推定手法は正確な既存データを利用した位置推定手法によるシーン解析，複数の測定点から位置を特定する三辺測量方法，隣接するノード間の近接情報を使った近接性方式がある．シーン解析は各測定点での正確な測定値のデータベースを構築する為のコストが高く，三辺測量方法では正確な地点が計測しにくく，近接性方式では正確な位置が分かった計測点（アンカー）が必要などの問題があった.

本研究は，モパイルレシーバーを使って複数の測定点で RSS を測定し電波を発するセンサーノードの位置を推定する．測定した RSS の値に基づいて位置測定に利用できるリファンレンスポイント（RP）及びインディケーターポイント（IP）という概念を導入し，この RP からどれだけ IP が離れているかを計算し，正確なセンサーノードの場所を絞り込んでいくという手法をとる．従来は，全ての通信可能なアンカーの位置の平均をセンサーノードの推定位置として利用した．このため，ノイズ環境によるアンカーの位置や信号データの誤差が免れないようになり，推定した位置の信頼性を保証することが困難である．本研究では，選択したアンカーの位置情報の分布を考慮して信頼度のレベルを判断することができるようになる.

本博士論文では，2 章で関連研究，3 章で位置測定点の信頼性の概念を述べた後，4 章で，RP を静的に固定した場合の位置推定手法を述べている．シミュレーションによる評価では，信頼度の高いと判断したセンサーノードの中から 89%のセンサーノードの誤差が改善できた.5 章では RP の位置を仮決めして，その位置を位置推定しながら徐々にセンサーノードに近づけていく動的な RP による位置推定手法を述べている．シミュレーションによる評価では 80%以上のセンサーノードが真の位置に対して，動的 RP による位置推定結果が 2m 以内の誤差であるという結果を得た.

センサーノードの利用場面は今後も広がると考えられ，位置推定はその発展を大きく推し進める技術の一つである．本研究のアプローチは極めて実践的であり，社会や産業での進展に貢献することが大であり，本博士論文の実用面での価値も大きいということができる．以上を総合して本審査委員会は，本論文が博士（応用情報科学）の学位授与に値するものと全員一致で判定した.