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The Application of SLAM Based on Extended Kalman Filteration

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Abstract. In this paper, there is a brief introduction about Kalman filteration. Then, analyze the working principle of Simultaneous Localization and Mapping, also called Concurrent Localization and Mapping. Give an introduction about different types of SLAM and the sensors required. After then, give some applications to the SLAM. A practical solution of laparoscopic sequence for surgery, which applied some feature that occur in the realistic use and overcome these obstacles. After then introduce a optimizing method for SLAM to be applied to embedded systems, using coprocessor to solve the calculation problem. Then is another algorithm that can be applied with SLAM to adapt different environments in space, which can automatically adjust the output voltage of different component to meet the scarcity of resources in space. Also introduce an application of algorithm to split the mapping of large scale to small scale map, which can increase the smoothness for closing loop route. Then suit the need for realistic world, give conclusion about different way of implementing multiple robots SLAM problem.

Keywords: Extended Kalman Filtering; Simultaneous Localization and Mapping; EKF; SLAM.

1. Introduction

From the start of robotic studies, errors exist in almost every data collected by sensors every second. Through out the development of sensors, one of the things developers always trying to fo is develop more accurate sensors with less error. Up to now, these advanced sensors can actually already solve many simple problems. However, for techniques like Simultaneous Localization and Mapping, they are still not accurate enough, hence occurs the need for optimizing algorithms.

Initially, assume that the surrounding consists of a wave or factor that affects the performance, and cause sensors to collect datas constantly larger or smaller a certain mean-square value. This value should be easily calculated because the static value. Then the real value should be easily calculated by minus or add this value. Then the effect of error wouldn't exist, this filtering method is called Wiener Filtering. However, this method can only filter out errors with constant mean-square value. Researchers than develop an filtering method based on the concept of assuming every error exists are following normal distribution, also model and system follow the linear relation at the same time. Under the assumption, the basic concept of it is using the state space model of signal and noise, using the assumption value from previous time and the current observed value to update the estimation to state variables, and getting the estimation value for future. For example, the case of data collected by a sensor on a moving object. First assuming the value without collecting value, create a diagram with either displacement or velocity on y axis, and the other on x axis. During the motion, the data collected would possibly following Gaussian distribution on both velocity and displacement. Finally, consider the relationship between displacement and velocity, the graph would be optimized to a distribution around y=x. Now create a second graph with same axis representative, and create Gaussian distribution about the collected value, which, potentially the true value without error would be on the graph. Then getting the coincide part of 2 graphs, the true value without error would possibly be in the part ideally. This is called Kalman Filteration.

This method and it's variations are known as the second-best way to minimize errors, can be seen as a huge variation of Wiener filteration, and it performs better than Wiener filteration. On the base of it, Extended Kalman Filteration is developed, which extends it to nonlinear cases. This essay talked about the Simultaneous Localization and Mapping technique based on the EKF, and the application for these. For SLAM, it's a technique used for robots to detect an environment and create map while moving in most efficient route, take a rough guess about which is the ideal route and map while the information captured are actually not enough to get the current location and route.

2. Operation Principle and Basic Information About SLAM Technique

2.1. Characteristics of SLAM

Moving to Simultaneous Localization and Mapping, also known as Concurrent Mapping and Localization. Based on the requirement of autonomous robots, after the collection of data and before the routing of robots, robots need to create a virtual map simultaneously to manage the route. The problem of this can be described as: When putting a robot into an unknown position in an unknown environment, are there any ways for robots to create a concurrent virtual map while deciding the appropriate direction for robots to go. One of the classic cases is the cleaning robot, to clean the whole room, it should avoid all the obstacles while approaching every bit of ground. While processing this problem, robots are processing 5 things at the same time. First, it would gather the characteristics of the surroundings. Then, it would recreate a virtual map in the processor so it can react or "memorize the environment". While it is moving, the sensors would gather information with error caused by the limited infrastructure of robots, hence the map created based on these data would also have error, so it also need to be adjusted based on the new collected data, which is the place where Wave Filtering work, to reduce error and save the work for this part. After then, it needs to be able to locate itself on the map it created, called trajectory. Final is the loop-closure detection aim to detect whether the robot moves into some place it has already been to. And all these 5 things are processed simultaneously in the SLAM.

There are also variations of SLAM, either Laser SLAM or Visual SLAM, Laser SLAM categorized deeper to 2D and 3D, While Visual SLAM is categorized to Sparse, semi-Dense and Dense, usually divided by the type of sensors/cameras. Laser SLAM implement based on laser radar. Visual SLAM implement based on camera, based on the information gathered by different type of camera. Camera can also be categorized into 5 main types, monocular, binocular, monocular structured light, binocular structured light and Time-Of-Flight camera. When implementing the SLAM algorithm, 4 main aspects are considered, how to show the map, how to detect the environment fully, how to solve the combination problem of data collected by different sensors, and how to create the virtual map while estimating current position, also some other relatively minor aspects, loop-closure detection, exploration and kidnapping. One of the famous Visual SLAM infrastructures is that the whole SLAM is first categorized to Front end and Back end. Front end responsible to analyze the relationship between each frequency, extract the characteristic points of each graph, match points by adjacent frequencies and using RANSAC to deduct large noise, getting a pose information and use Inertial measurement unit for filter fusion. At the back end, it mainly optimizes the result of front-end using variation of KF or other theories. However, for EKF, the requirement of enormous numbers of inverse kinematic calculations pressured the processor a lot and limited the use of EKF based SLAM, also because the use of EKF, the map made is prior to smoother, result in the fact that it's hard to connect the map when getting to same location again.

2.2. Different type of SLAM

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3. Applications Of SLAM

Based on the development of EKM and SLAM algorithms, many application variations are proposed. This technique shows great talent in exerting a same verb event, not exactly same environment but same things such as cooking. Showing great advantage comparing to the traditional code a program each time. At the same time, considering the performance and requirements on different applications, apparently the ideal solution for different applications would be different. For example, ideally cheap floor mopping robot with less mapping accuracy required, and high mapping accuracy required surgery robots with less price requirement.

Surgery is one of the most common applications of SLAM algorithms. The fact that each human has the same body and organ, but different sizes produced a perfect use of SLAM, robots need to identify the organs and blood vessels, and the exact shape of them. For example, the application of SLAM in laparoscopic sequence. The challenges of laparoscopic sequence come from 4 main factors, first is the cluttering produced by tools, the surgery require abdominal cavity model with only body of patients without tools inside , second is the sudden motions of the camera, then is the applying in reality causing laparoscope would frequent goes in and out of abdominal cavity, so it need to know precisely the location it's in, final is the tissue deformation caused by the respiration, because organs aren't fixed in same position, surgical tools, heartbeat and even laparoscope itself might cause the organs in the abdominal cavity to move randomly, hence affecting the inaccurate of previous made model, so when SLAM is used in this situation, it had to know clearly about which one is the tools and which one is the vibrating organs [1]. The combination of EKF Monocular SLAM, 1-point Random Sample Consensus and Randomized List Relocalization can solve the laparoscopic sequences and model the abdominal cavity [1]. Using EKF to minimize the error of data at that time, SLAM to create map, using 1-point Random Sample Consensus to further minimize error and get validated data, Randomized List relocalization to finally solve the precision problem [1]. By consider more factors comparing to the previous solution using EKF SLAM, it's able to solve this problem with cluttering produced by tools and more tissue deformations [2]. By combining 1-point Random sample consensus and Randomized List Relocalization solve this problem realistically Fig.1 [3,4].

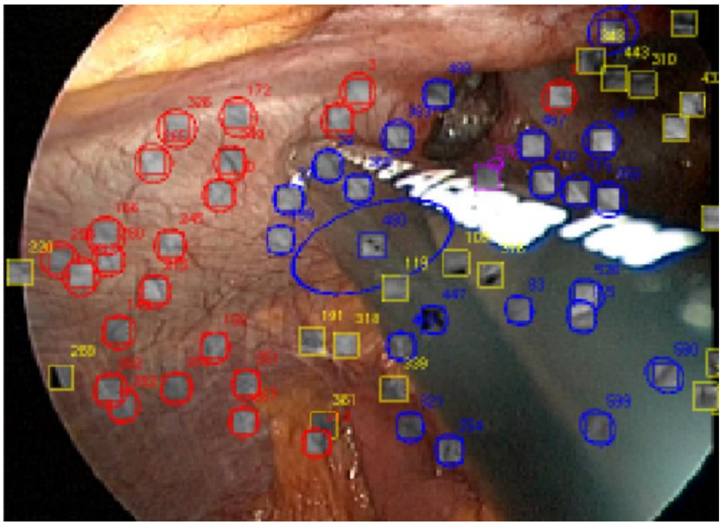

Fig. 1 A sample image of data collected by laporascopic sequence: the characteristic of organs and blood vessels in the enterocoelia is shown for doctor, for which different information is categorized and marked by different colors, square for possible exist feature and circle for all the possible place the vessels might in [1].

Because the enormous inverse kinematic calculations involved in the Simultaneous process of EKF, in order to exert it on robots, robots had to have a strong enough processor to process it, hence increase the cost of whole robot, making it relatively hard to be utilized on embedded systems which is designed to maintain certain level of processing speed while lower the cost. However, by using a more efficient optimizing computing method, it's possible to solve this problem [5]. Solving this problem by optimizing the problem from two sides, making the algorithm more efficient and enhancing the robot's ability to process the algorithm [5]. Based on the concept of coprocessor and more efficient EKF method, the cost of the whole system decreases ideally, suiting the likely application of this technique [5]. It combines Single Instruction, Multiple Data to the current variation of EKF-SLAM [5]. Under real time constraints, implemented the EKF-SLAM possible robots to cost friendly multi-core architecture. Ideally, it broadens the accessibility of this type of robot to the public approachable market. Giving a cheap solution for robots used daily like floor mopping robot or autonomous driving.

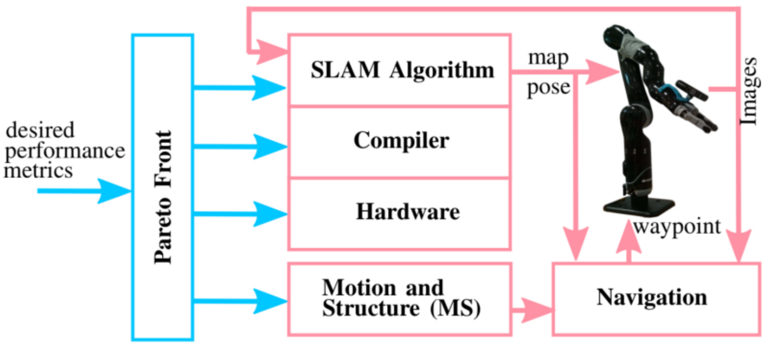

Fig. 2 A sample graph of the structure of SLAM mentioned in space SLAM: it shows a structure chart for the rough data transferred between different components and how the function of robots is divided [6].

Based on the working space of robots, the ideal solution would also vary Fig. 2, and hence opened the studied of designed space exploration [6]. By considering comprehensive design space, structure and motion space, this survey solves the conversion from earth-based theories and algorithms to space-based situations, such as the processing of information captured in highly dynamic space. Using information theory as bases to parameterize the motion and structure space [6]. One of the important uses of this theory is that, after parameters are already identified, because the possibly exist uncertainty might cause the information divergence to exceed expected value and causing low performance, this can be solved by choosing another set of parameters [6]. It makes it possible for robots to change to different sets of parameters under different situations, hence able to adapt the diversity of space without human regulations, and alter the processing speed based on limited resources in space [6]. Implement the possibility to use a crucial portion of autonomous, applying SLAM to individual dependent space robots.

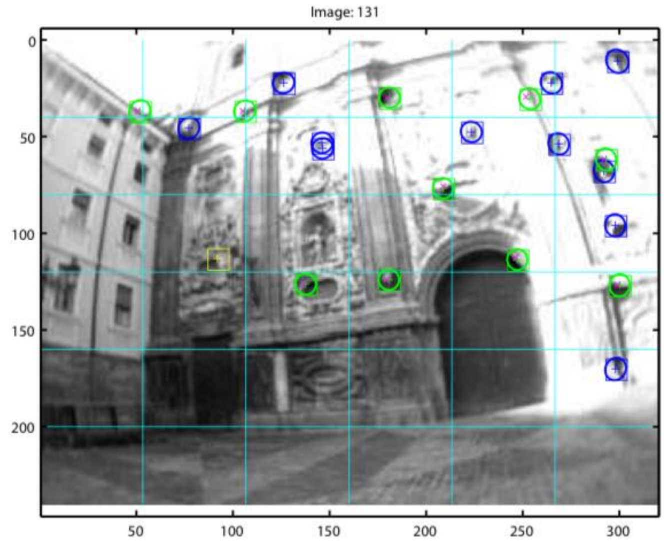

Fig. 3 A sample image of the connection between small map and integrated map [7].

Also, large scale slam building local maps is one of the applications of SLAM. Despite the success achieved by EKF based SLAM, there are some limitations, first is that the approximation involve in the linearization of EKF might cause inconsistency in map, second is it require to update the full map covariance matrix after each measurement, giving a memory complexity and time complexity. These 2 limitations are likely solved by [7]. According to the essay, intuitive is that because the map is split into small maps Fig.3, the errors of these small maps would likely to be small, causing the linearization error to also be small, solving the consistency error, also, the fact is that small maps allow data association of direct implementation since they work with covariance matrices, optimize the problem. These researchers contribute mainly to introducing a novel technique that enables splitting map algorithms, sharing information between maps, and remaining conditionally independent. It enables the recovery of global maps after simple loop closures. The use of this technique enables robots to exert in relatively large environments, optimize the drawbacks of EKF based SLAM, obtain an approximate scale for the map by choosing appropriate value of initial velocity and the covariance of the process noise [7]. Act as a crucial role for robots to be used frequently in complex cities environments.

Moving back to the initial purpose of SLAM, when people want to explore a place and make a map, the fact is that the ideal number or most efficient number of robots to complete the mission apparently shouldn't be 1. Despite the consideration of average efficiency of each robot, the total efficiency combined by different robots apparently should be more the better. However, as the number of robots increases, the need for combining algorithms occurs, for which combine the information of each robot and plan their individual route. Also, the complexity of algorithms comes with the efficiency of it. In the modern world, there are few approaches. One of the initial approaches is mentioned of trying to resolve the potential conflict between different robots and get a route for each robot by coordination with prioritization [8]. Then the first coordination technique is introduced, avoiding collisions by moving with occasionally stops and backward [8]. After then is a significant approach of applying A* planner [8]. Since the unexcavated of this area, another branch of approach also exists, what is called hierarchical planning. The concept of it is to implement the task by the knowledge from both dynamic and static world. Using global planner in the base of static knowledge to plan the route from start post to goal, then use dynamic knowledge for local planner, planning the avoidance of obstacles, and message delivered by potential field planner, this is seen as one of the solutions for multirobot collision-free motion [8].

Occupying over 70% of the surface area of earth, ocean is also one of the adventures places of human that lack exploration, the property of water and the characteristics of ocean current result in the fact that the problem of SLAM can't be treated the same way as the problem on land. In the essay, a solution is given to this problem. They use an upward-facing stereo camera combined with sparse features to build a global ceiling feature map. Then, since the camera is out of water, there would be a problem of refraction, what captured by camera wasn't the true feature of underwater. However, this can be solved by the combination of triangulation functions and refraction-corrected projection [9]. Finally, optimize the performance of robots odometry and point landmark part by the incremental smoothing and mapping backend [9]. This solution shows adequate performance over test-tank environment, however, haven't been tested in more complex environments.

4. Conclusion

Simultaneous Localization and Mapping technique have already been one of the crucial bases of modern robotics. Throughout the paper, some applications are based on the concept of SLAM. First is about a application in surgery, introduce Usable laparoscopic sequence that is developed with the consideration of real life applying, considering the deformation of graph caused by the vibrating of organs, interference of surgery tools, also the frequent in and out of abdominal cavity. Then introduce a way to overcome the architecture and calculation speed of embedded systems, solve the limitations of clock speed, and introduce coprocessors to improve the performance. Introduce some new structure of SLAM in applying to space environment, also some algorithms to alter the base structure of SLAM when facing different environments, introduce adaptivity when experiencing space environment. An optimizing algorithm of SLAM, that improve efficiency by splitting the mapping part of SLAM to subroutines that responsible for either creating small portions of graph or integrate the information of each graph together, allowing to implement smoother mapping. Finally conclude some exploration about the multiple robot SLAM problem, and conclude the currently most efficient approach. Finally introduce a solution about underwater SLAM technique that implement it in the air. Overall, introduce some applications of SLAM and some extensions of the basic SLAM salgorithms.

Until now, SLAM algorithm is a new developed algorithm. However, already show its potential and adaptivity across multiple environments. In the future, the exploration might keep the current pace, exploring more efficient and accurate SLAM algorithms, getting a second-best solution. Or exploring the solution across multiple robots' SLAM. The development of SLAM should also vary with the type of robot arm they have, or the fans and different type of movement structures. The direction of some robots with these movement mechanisms can't be changed easily, they can't move whatever the algorithm command them. The characteris of them required new variation of SLAM algorithms.

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