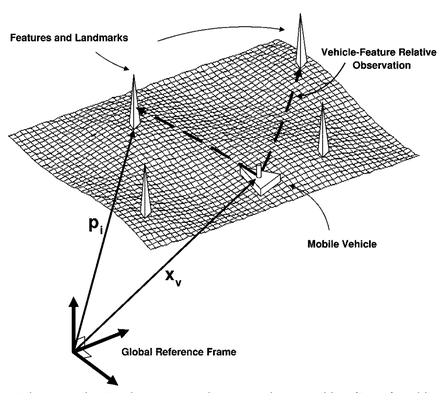
Simultaneous Localization and Mapping

Matthew Thompson, UF
matthewbot@ufl.edu

The Problem

Simultaneous Localization and Mapping, or SLAM, is a problem in the field of autonomous vehicles. Its solution, only found in the last decade, has been called "a 'Holy Grail' of the autonomous vehicle research community" [3]. Until several papers released in 2001 detailed new approaches to approaching SLAM, most roboticists had either studied mapping unknown environments using a robot which always knew its exact position, or determining the position of a robot which already had advance knowledge of its surroundings [6]. SLAM, true to its name, is the problem of performing both of the tasks simultaneously, without prior information about the environment *or* the robot's own position. It is a rather akin to the question of "which came first, the chicken or the egg?" [6]. To build an accurate map of its environment, a robot needs to first know its own position in the world, yet in order to determine its position, the robot must first have an accurate map of its environment.

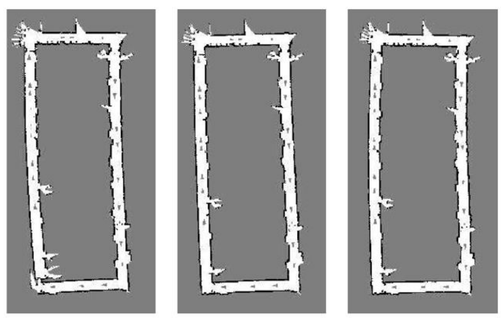


A Solution to the Simultaneous Localization and Map Building (SLAM) Problem
Dissanayake G, Newman P, Clark S

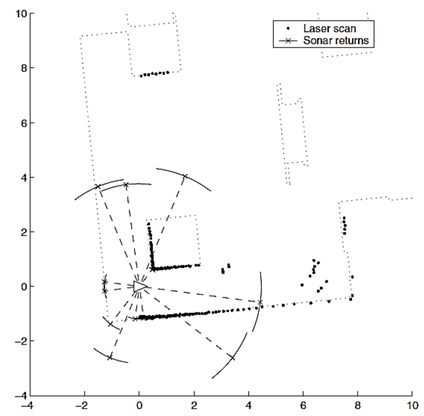
The Solution and Ongoing Research

Although no one SLAM technique is clearly best, and indeed even among the mort important papers listed here there are varied solutions, most take an estimation-theoretic approach using a Kalman Filter [1]. The Kalman filter is a widely used method of processing uncertain measurements and producing an optimal estimate of the actual state of a system. The estimation-theoretic has been successfully implemented many times, and has been proven to converge to an ideal map and perfect robot position even in the face of noisy measurements and uncertainty in the robot's motion [3].

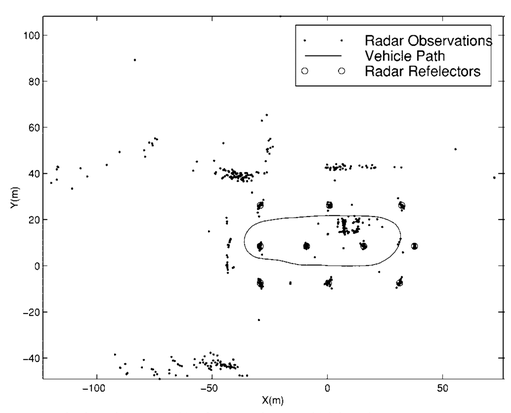
Ongoing research covers many improvements to the basic approach. For large environments the storage requirements of the naïve approach grow too quickly, and so research is done in exploring potentially valuable trade offs in changing the underlying implementation of the map [1][5]. Experiments are also ongoing in achieving SLAM using sensors other than a LIDAR scanner, such as a sonar array [7]. Another area is improving the efficiency of methods used for relaxation of the robot's map, a process used to "close the loop" when a robot has traveled in a circle and senses previously mapped landmarks but at a different estimated position due to accumulated error [6].



Closing the loop after traveling along a rectangular hallway
A multilevel Relaxation Algorithm for Simultaneous Localization and Mapping
Frese U, Larsson P, Ducket T



Sonar and LIDAR readings compared
Robust Mapping and Localization in Indoor Environments Using Sonar Data
Tardos, Neira, Newman, Leonard



A radar-based SLAM tracking features along a vehicle's path
A Solution to the Simultaneous Localization and Map Building (SLAM) Problem
Dissanayake G, Newman P, Clark S, Durrant-Whyte H, Csorba M

Applications

SLAM has had very immediate applications in autonomous vehicles such as those participating in the DARPA Grand Challenge. SLAM is also important for indoor robots, since it can calculate the position of a robot in the absence of GPS. It represents a huge step towards future domestic robots that interact and work with humans in a human-centric world, where the robots will have to learn for themselves and will be expected to adapt to an already existing environment. Another important application is search and rescue robots that could aid disaster response teams by quickly and efficiently mapping a disaster site and reporting back the location of survivors.

Activmedia Peoplebot exploring an environment
A multilevel Relaxation Algorithm for Simultaneous Localization and Mapping
Frese U, Larsson P, Ducket T

NaviGATOR, from the Center for Intelligent Machines and Robotics at the University of Florida
http://www.research.ufl.edu/publications/explore/v11n1/story2.html

Prolific Authors

Name	Total Papers
Dissanayake, G	11
Ball, T	10
Newman, P	10
Nuchter, A	9
Rajamani, SK	9
Neira, J	8
Grisetti, G	8
Leonard, JJ	7

Important Papers

Title	Year	Times Cited	Institutions or Organizations
Simultaneous map building and localization for an autonomous mobile robot	1991	N/A (Conference proceedings)	Princeton, University of Oxford
Topological simultaneous localization and mapping (SLAM): toward exact localization without explicit localization	2001	175	Carnegie Mellon
A solution to the simultaneous localization and map building (SLAM) problem	2001	407	IEEE
Optimization of the simultaneous localization and map-building algorithm for real-time implementation	2001	212	IEEE
Robust Mapping and Localization in Indoor Environments Using Sonar Data	2002	156	University Zaragoza, MIT
A multilevel relaxation algorithm for simultaneous localization and mapping	2005	49	IEEE
MonoSLAM: Real-Time Single Camera SLAM	2007	118	IEEE

Prolific Institutions

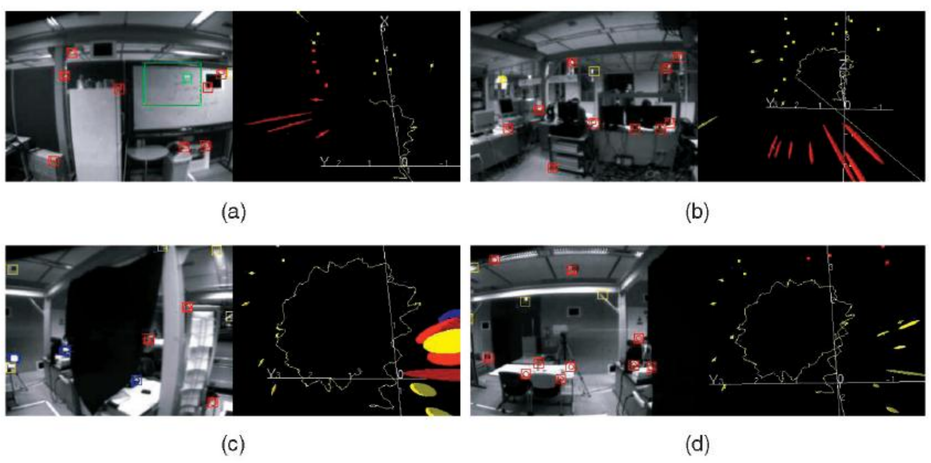
Name	Papers
University of Sydney	25
MIT	15
University Zaragoza	15
University of Oxford	12

Top Journals

Name	Papers	Impact Factor
International Journal of Robotics Research	40	1.993
IEEE Transactions on Robotics	39	2.035
Robotics and Autonomous Systems	36	1.361
Journal of Field Robotics	25	1.989

Key Paper

MonoSLAM: Real-Time Single Camera SLAM, stands out on the list of highly cited papers as the most recent, as well as the only paper whose number of citations per year is still increasing. It takes a breakthrough approach to SLAM by achieving it with a single camera [2]. This presents a very difficult SLAM scenario, because a single camera gives lots of high speed data to process but no direct distance measurements [2]. Technology exists to recreate the motion of a camera passing through a static environment, but only offline, processing the entire sequence from beginning to end. MonoSLAM gives a technique whereby estimates of the camera position and the map of the environment its in can be updated with each new frame of information acquired in real time [2], and can travel in a fixed environment indefinitely while maintaining a bounded error [2], while being efficient enough to operate at an update rate of 30hz [2].



Snapshots of a humanoid robot running MonoSLAM software on a single camera as it walks in a circle.
MonoSLAM: Real-Time Single Camera SLAM
Davison A, Reid I, Molton N, Stasse O

References

1. Choset, H., & Nagatani, K. (2001). Topological simultaneous localization and mapping (SLAM): Toward exact localization without explicit localization. *Robotics and Automation, IEEE Transactions on, 17*(2), 125-137.
2. Davison, A. J., Reid, I. D., Molton, N. D., & Stasse, O. (2007). MonoSLAM: Real-time single camera SLAM. *Pattern Analysis and Machine Intelligence, IEEE Transactions on, 29*(6), 1052-1067.
3. Dissanayake, M. W. M. G., Newman, P., Clark, S., Durrant-Whyte, H. F., & Csorba, M. (2001). A solution to the simultaneous localization and map building (SLAM) problem. *Robotics and Automation, IEEE Transactions on, 17*(3), 229-241.
4. Frese, U., Larsson, P., & Duckett, T. (2005). A multilevel relaxation algorithm for simultaneous localization and mapping. *Robotics, IEEE Transactions on, 21*(2), 196-207.
5. Guivant, J. E., & Nebot, E. M. (2001). Optimization of the simultaneous localization and map-building algorithm for real-time implementation. *Robotics and Automation, IEEE Transactions on, 17*(3), 242-257.
6. Leonard, J. J., & Durrant-Whyte, H. F. (1991). Simultaneous map building and localization for an autonomous mobile robot. *Intelligent Robots and Systems '91. 'Intelligence for Mechanical Systems, Proceedings IROS '91. IEEE/RSJ International Workshop on,* 1442-1447 vol.3.
7. Tardós, J. D., Neira, J., Newman, P. M., & Leonard, J. J. (2002). Robust mapping and localization in indoor environments using sonar data. *The International Journal of Robotics Research, 21*(4), 311-330.