|  |  |
| --- | --- |
|  | This paper outline is as follows:  Section 2 presents an overview of SLAM problem and various approaches to solve it (Statistical/vision based/computational).  1985 Chatila & Laumond Position referencing and consistent world modeling for mobile robots R. Chatila and J. Laumond, "Position referencing and consistent world modeling for mobile robots," Proceedings. 1985 IEEE International Conference on Robotics and Automation, St. Louis, MO, USA, 1985, pp. 138-145, doi: 10.1109/ROBOT.1985.1087373.  In order to understand its environment, a mobile robot should be able to model consistently this environment, and to locate itself correctly. One major difficulty to be solved is the inaccuracies introduced by the sensors. The approach proposed in this paper to cope with this problem relies on 1) defining general principles to deal with uncertainties : the use of a multisensory system, favo ring of the data collected by the more accurate sensor in a given situation, averaging of different but consistent measurements of the same entity weighted with their associated uncertainties, and 2) a methodology enabling a mobile robot to define its own reference landmarks while exploring its environment. These ideas are presented together with an example of their application on the mobile robot HILARE.  1986 R.C. Smith and P. Cheeseman On the Representation and Estimation of Spatial Uncertainty  * February 1987 * [The International Journal of Robotics Research](https://www.researchgate.net/journal/The-International-Journal-of-Robotics-Research-1741-3176?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19) 5(4)   This paper describes a general method for estimating the nominal relationship and expected error (covariance) between coordinate frames representing the relative locations of objects. The frames may be known only indirectly through a series of spatial relationships, each with its associated error, arising from diverse causes, including positioning errors, measurement errors, or tolerances in part dimensions. This estimation method can be used to answer such questions as whether a camera attached to a robot is likely to have a particular reference object in its field of view. The calculated estimates agree well with those from an independent Monte Carlo simulation. The method makes it possible to decide in advance whether an uncertain relationship is known accurately enough for some task and, if not, how much of an improvement in locational knowledge a proposed sensor will provide. The method presented can be generalized to six degrees of freedom and provides a practical means of estimating the relationships (position and orientation) among objects, as well as estimating the uncertainty associated with the relationships.  Simultaneous map building and localization for an autonomous mobile robot.  John J Leonard, Hugh F Durrant-Whyte 1991  Discusses a significant open problem in mobile robotics: simultaneous map building and localization, which the authors define as long-term globally referenced position estimation without a priori information. This problem is difficult because of the following paradox: to move precisely, a mobile robot must have an accurate environment map; however, to build an accurate map, the mobile robot's sensing locations must be known precisely. In this way, simultaneous map building and localization can be seen to present a question of 'which came first, the chicken or the egg?' (The map or the motion?) When using ultrasonic sensing, to overcome this issue the authors equip the vehicle with multiple servo-mounted sonar sensors, to provide a means in which a subset of environment features can be precisely learned from the robot's initial location and subsequently tracked to provide precise positioning. Localization of Autonomous Guided Vehicles H. Durrant-Whyte, D. Rye, E. Nebot  Published 1996  Abstract  This paper reviews and describes the state-of-the-art in localization of autonomous guided vehicles (AGVs). The localization problem, the ability to accurately sense and estimate the location of a platform, lies at the heart of almost all AGV applications. Solving the localization problem is an essential precursor to more complex AGV tasks such as planing and task execution. **Globally Consistent Range Scan Alignment for Environment Mapping** Lu and Milios  A robot exploring an unknown environment may need to build a worldmodel from sensor measurements. In order to integrate all the framesof sensor data, it is essential to align the data properly. Anincremental approach has been typically used in the past, in whicheach local frame of data is aligned to a cumulative global model, andthen merged to the model. Because different parts of the model areupdated independently while there are errors in the registration,such an approach may result in an inconsistent model.  In this paper, we study the problem of consistent registration ofmultiple frames of measurements (range scans), together with therelated issues of representation and manipulation of spatialuncertainties. Our approach is to maintain all the local frames ofdata as well as the relative spatial relationships between localframes. These spatial relationships are modeled as random variablesand are derived from matching pairwise scans or from odometry. Thenwe formulate a procedure based on the maximum likelihood criterion tooptimally combine all the spatial relations. Consistency is achievedby using all the spatial relations as constraints to solve for thedata frame poses simultaneously. Experiments with both simulated andreal data will be presented. [FastSLAM: A factored solution to the simultaneous localization and mapping problem](https://cdn.aaai.org/AAAI/2002/AAAI02-089.pdf) M **Montemerlo**, [S **Thrun**](https://scholar.google.co.in/citations?user=q-buMEoAAAAJ&hl=en&oi=sra), [D **Koller**](https://scholar.google.co.in/citations?user=5Iqe53IAAAAJ&hl=en&oi=sra), B **Wegbreit**  The ability to simultaneously localize a robot and accurately map its surroundings is considered by many to be a key prerequisite of truly autonomous robots. However, few approaches to this problem scale up to handle the very large number of landmarks present in real environments. Kalman filter-based algorithms, for example, require time quadratic in the number of landmarks to incorporate each sensor observation. This paper presents FastSLAM, an algorithm that recursively estimates the full posterior distribution over robot pose and landmark locations, yet scales logarithmically with the number of landmarks in the map. This algorithm is based on an exact factorization of the posterior into a product of conditional landmark distributions and a distribution over robot paths. The algorithm has been run successfully on as many as 50,000 landmarks, environments far beyond the reach of previous approaches. Experimental results demonstrate the advantages and limitations of the FastSLAM algorithm on both simulated and realworld data. RatSLAM: a hippocampal model for simultaneous localization and mapping Milford, Wyeth, Prasser Abstract: The work presents a new approach to the problem of simultaneous localization and mapping - SLAM - inspired by computational models of the hippocampus of rodents. The rodent hippocampus has been extensively studied with respect to navigation tasks, and displays many of the properties of a desirable SLAM solution. RatSLAM is an implementation of a hippocampal model that can perform SLAM in real time on a real robot. It uses a competitive attractor network to integrate odometric information with landmark sensing to form a consistent representation of the environment. Experimental results show that RatSLAM can operate with ambiguous landmark information and recover from both minor and major path integration errors.  **Improved Techniques for Grid Mapping With Rao-Blackwellized Particle Filters**  Grisetti, Giorgio and Stachniss, Cyrill and Burgard, Wolfram Abstract: Recently, Rao-Blackwellized particle filters (RBPF) have been introduced as an effective means to solve the simultaneous localization and mapping problem. This approach uses a particle filter in which each particle carries an individual map of the environment. Accordingly, a key question is how to reduce the number of particles. In this paper, we present adaptive techniques for reducing this number in a RBPF for learning grid maps. We propose an approach to compute an accurate proposal distribution, taking into account not only the movement of the robot, but also the most recent observation. This drastically decreases the uncertainty about the robot's pose in the prediction step of the filter. Furthermore, we present an approach to selectively carry out resampling operations, which seriously reduces the problem of particle depletion. Experimental results carried out with real mobile robots in large-scale indoor, as well as outdoor, environments illustrate the advantages of our methods over previous approaches  W. Shiguang and W. Chengdong,  "An improved FastSLAM2.0 algorithm using Kullback-Leibler Divergence,"  2017 Abstract: The ability to simultaneously localize a robot and map its surroundings is considered by many to be a key prerequisite of truly autonomous robots. However, there is a dilemma between accuracy and computational complexity in existing SLAM algorithms. EKFSLAM algorithm, developed by Smith R in 1988, was first applied in SLAM. Nevertheless, high computational complexity became one of the main barriers for wide spread usage. To reduce the computational consumption, a new method based on conditional probability decomposition was used in FastSLAM, which makes the running time a logarithmic function of landmarks. Then the following FASTSLAM2.0 algorithm fused the proposed distribution with observation information, and it raised algorithm accuracy effectively. Aiming at the degeneracy problem in FastSLAM2.0, an improved resampling method using Kullback-Leibler Divergence is put forward, which contains particle degeneration largely. Simulation results show that this approach accelerates the convergence of particles set and restrains particle depletion as well.  A. Murangira, C. Musso and K. Dahia,  "A mixture regularized rao-blackwellized particle filter for terrain positioning,"  2016 Abstract: This study is concerned with the development of a robust particle filtering algorithm tailored to the problem of terrain-aided positioning (TAP) via radar altimeter measurements. The Rao-Blackwellized particle filter (RBPF) is a popular particle filtering algorithm for TAP that takes advantage of the nature of the state-space model by sampling particles in a subspace of the state space, yielding more efficient estimators than the standard particle filter. Like most Monte Carlo filters, the standard RBPF uses the transition kernel as the proposal distribution during the particle update step. However, in contexts where the likelihood function is peaky, this may be highly inefficient since samples may fall in regions of low posterior probability. To address this issue, it is often advocated to use an importance sampling density that takes into account the latest observation. In a sequential importance sampling context, an optimal importance density is available but can be easily sampled only for specific state-space models, which raises the question of how to design a proposal density that is efficient yet easy to sample from. In this paper, we propose a particle filtering importance sampling method adapted to multimodal distributions. It hinges on the use of a robust proposal density as well as a cluster-based representation of the multimodal posterior. This leads to a novel marginalized particle filter, the regularized RBPF, that is evaluated on a challenging terrain positioning application.  Zhao, Wang, Qin, & Zhang 2018  Woo 2019 **Simultaneous Localization and Mapping Based on Kalman Filter and Extended Kalman Filter** Inam Ullah, Xin Su, Xuewu Zhang, Dongmin Choi  2020  For more than two decades, the issue of simultaneous localization and mapping (SLAM) has gained more attention from researchers and remains an influential topic in robotics. Currently, various algorithms of the mobile robot SLAM have been investigated. However, the probability-based mobile robot SLAM algorithm is often used in the unknown environment. In this paper, the authors proposed two main algorithms of localization. First is the linear Kalman Filter (KF) SLAM, which consists of five phases, such as (a) motionless robot with absolute measurement, (b) moving vehicle with absolute measurement, (c) motionless robot with relative measurement, (d) moving vehicle with relative measurement, and (e) moving vehicle with relative measurement while the robot location is not detected. The second localization algorithm is the SLAM with the Extended Kalman Filter (EKF). Finally, the proposed SLAM algorithms are tested by simulations to be efficient and viable. The simulation results show that the presented SLAM approaches can accurately locate the landmark and mobile robot.  Davison,  "Real-time simultaneous localisation and mapping with a single camera” Abstract: Ego-motion estimation for an agile single camera moving through general, unknown scenes becomes a much more challenging problem when real-time performance is required rather than under the off-line processing conditions under which most successful structure from motion work has been achieved. This task of estimating camera motion from measurements of a continuously expanding set of self-mapped visual features is one of a class of problems known as Simultaneous Localisation and Mapping (SLAM) in the robotics community, and we argue that such real-time mapping research, despite rarely being camera-based, is more relevant here than off-line structure from motion methods due to the more fundamental emphasis placed on propagation of uncertainty. We present a top-down Bayesian framework for single-camera localisation via mapping of a sparse set of natural features using motion modelling and an information-guided active measurement strategy, in particular addressing the difficult issue of real-time feature initialisation via a factored sampling approach. Real-time handling of uncertainty permits robust localisation via the creating and active measurement of a sparse map of landmarks such that regions can be re-visited after periods of neglect and localisation can continue through periods when few features are visible. Results are presented of real-time localisation for a hand-waved camera with very sparse prior scene knowledge and all processing carried out on a desktop PC. Parallel tracking and mapping for small AR workspaces G Klein, D Murray  2007  This paper presents a method of estimating camera pose in an unknown scene. While this has previously been attempted by adapting SLAM algorithms developed for robotic exploration, we propose a system specifically designed to track a hand-held camera in a small AR workspace. We propose to split tracking and mapping into two separate tasks, processed in parallel threads on a dual-core computer: one thread deals with the task of robustly tracking erratic hand-held motion, while the other produces a 3D map of point features from previously observed video frames. This allows the use of computationally expensive batch optimisation techniques not usually associated with real-time operation: The result is a system that produces detailed maps with thousands of landmarks which can be tracked at frame-rate, with an accuracy and robustness rivalling that of state-of-the-art model-based systems.  **ORB-SLAM: A Versatile and Accurate Monocular Slam System.**  Mur-Artal, R., Montiel, J.M.M. and Tardos, J.D. (2015)  This paper presents ORB-SLAM, a feature-based monocular SLAM system that operates in real time, in small and large, indoor and outdoor environments. The system is robust to severe motion clutter, allows wide baseline loop closing and relocalization, and includes full automatic initialization. Building on excellent algorithms of recent years, we designed from scratch a novel system that uses the same features for all SLAM tasks: tracking, mapping, relocalization, and loop closing. A survival of the fittest strategy that selects the points and keyframes of the reconstruction leads to excellent robustness and generates a compact and trackable map that only grows if the scene content changes, allowing lifelong operation. We present an exhaustive evaluation in 27 sequences from the most popular datasets. ORB-SLAM achieves unprecedented performance with respect to other state-of-the-art monocular SLAM approaches. For the benefit of the community, we make the source code public.  **Orb-slam2: An open-source slam system for monocular, stereo, and rgb-d cameras.**  Mur-Artal, R., & Tard´os, J. D. (2017). Abstract: We present ORB-SLAM2, a complete simultaneous localization and mapping (SLAM) system for monocular, stereo and RGB-D cameras, including map reuse, loop closing, and relocalization capabilities. The system works in real time on standard central processing units in a wide variety of environments from small hand-held indoors sequences, to drones flying in industrial environments and cars driving around a city. Our back-end, based on bundle adjustment with monocular and stereo observations, allows for accurate trajectory estimation with metric scale. Our system includes a lightweight localization mode that leverages visual odometry tracks for unmapped regions and matches with map points that allow for zero-drift localization. The evaluation on 29 popular public sequences shows that our method achieves state-of-the-art accuracy, being in most cases the most accurate SLAM solution. We publish the source code, not only for the benefit of the SLAM community, but with the aim of being an out-of-the-box SLAM solution for researchers in other fields. ProSLAM: Graph SLAM from a Programmer's PerspectiveD. Schlegel, Mirco Colosi, G. Grisetti Abstract  In this paper we present ProSLAM, a lightweight open-source stereo visual SLAM system designed with simplicity in mind. This work stems from the experience gathered by the authors while teaching SLAM and aims at providing a highly modular system that can be easily implemented and understood. Rather than focusing on the well known mathematical aspects of stereo visual SLAM, we highlight the data structures and the algorithmic aspects required to realize such a system. We implemented ProSLAM using the C++ programming language in combination with a minimal set of standard libraries. The results of a thorough validation performed on several standard benchmark datasets show that ProSLAM achieves precision comparable to state-of-the-art approaches, while requiring substantially less computation. Stereo visual SLAM for autonomous vehicles: A review B Gao, H Lang, J Ren  2020  Simultaneous Localization and Mapping (SLAM) problem, where an autonomous vehicle moving in an unknown environment attempts to sense and map its surroundings while recognizing its own location and trajectory within the map, has always been a notable and popular research topic in the field of computer vision, robotics and artificial intelligence. Among the various types of solutions relying on different sensor modalities such as the global positioning system (GPS), radio signals, lidar, etc., vision-based solutions are of major interest nowadays because most cameras are low-cost and rich information gathering, especially for the stereo cameras. In this paper, different technologies of visual SLAM, where the main sensors are cameras, are surveyed with an emphasis on methodologies using stereo cameras. Some state-of-the-art open-source stereo visual SLAM frameworks are also discussed and compared. Finally, a general discussion of the challenges in terms of accuracy, processing time, cost, etc. is provided. The main purpose of this review is to provide a comprehensive overview of public available stereo visual SLAM frameworks and their corresponding pros and cons in different real-world scenarios.  G. Grisetti, C. Stachniss and W. Burgard,  "Improved Techniques for Grid Mapping With Rao-Blackwellized Particle Filters,"  2007  Recently, Rao-Blackwellized particle filters (RBPF) have been introduced as an effective means to solve the simultaneous localization and mapping problem. This approach uses a particle filter in which each particle carries an individual map of the environment. Accordingly, a key question is how to reduce the number of particles. In this paper, we present adaptive techniques for reducing this number in a RBPF for learning grid maps. We propose an approach to compute an accurate proposal distribution, taking into account not only the movement of the robot, but also the most recent observation. This drastically decreases the uncertainty about the robot's pose in the prediction step of the filter. Furthermore, we present an approach to selectively carry out resampling operations, which seriously reduces the problem of particle depletion. Experimental results carried out with real mobile robots in large-scale indoor, as well as outdoor, environments illustrate the advantages of our methods over previous approaches  Three new Iterative Closest Point variant-methods that improve scan matching for surface mining terrain  F.A. Donoso and K.J. Austin and P.R. McAree  2017  keywords = {Iterative Closest Point, Terrain mapping, Point cloud registration algorithms, Entropy measures, Eigentropy},  The Iterative Closest Point (ICP) algorithm seeks to minimize the misalignment between two point cloud data sets. A limitation of many ICP algorithms is that they work well for some contexts, yet perform poorly in others. Previous work has suggested that the ability of ICP variants to find correspondence was hindered by the presence of geometric disorder in the scene. This paper introduces three new methods based on characterizing the geometric properties of a point using information of its nearest neighbours. Two methods are entropy based and quantify the geometric disorder (eigentropy) in order to improve the filtering of data and thereby remove points that are likely to provide spurious associations. The third method is a point matching method using normals to preferentially work with planar areas of a point cloud. A set of 73,728 ICP variants obtained by combination/permutation of 26 methods are evaluated. These variants were evaluated using a scan matching exercise requiring construction of terrain maps based on data from a mobile sensing platform in an open-cut mining environment. The proposed methods improve ICP performance, as measured by accuracy, precision, and computational efficiency. Notably, five ICP variants, each featuring the new methods of this paper, simultaneously met the solution requirements for three different terrain scenes. It is asserted that being able to characterize the geometric disorder in the point clouds improves the capability of ICP to establish associations between points.  R. A. Newcombe, S. J. Lovegrove and A. J. Davison  "DTAM: Dense tracking and mapping in real-time,"  2011  DTAM is a system for real-time camera tracking and reconstruction which relies not on feature extraction but dense, every pixel methods. As a single hand-held RGB camera flies over a static scene, we estimate detailed textured depth maps at selected keyframes to produce a surface patchwork with millions of vertices. We use the hundreds of images available in a video stream to improve the quality of a simple photometric data term, and minimise a global spatially regularised energy functional in a novel non-convex optimisation framework. Interleaved, we track the camera's 6DOF motion precisely by frame-rate whole image alignment against the entire dense model. Our algorithms are highly parallelisable throughout and DTAM achieves real-time performance using current commodity GPU hardware. We demonstrate that a dense model permits superior tracking performance under rapid motion compared to a state of the art method using features; and also show the additional usefulness of the dense model for real-time scene interaction in a physics-enhanced augmented reality application.  MobileFusion: Real-time Volumetric Surface Reconstruction and  Dense Tracking On Mobile Phones  Peter Ondr ´uˇska, Pushmeet Kohli and Shahram Izadi  2015  Abstract—We present the first pipeline for real-time volumetric surface reconstruction and dense 6DoF camera tracking running purely  on standard, off-the-shelf mobile phones. Using only the embedded RGB camera, our system allows users to scan objects of varying  shape, size, and appearance in seconds, with real-time feedback during the capture process. Unlike existing state of the art methods,  which produce only point-based 3D models on the phone, or require cloud-based processing, our hybrid GPU/CPU pipeline is unique  in that it creates a connected 3D surface model directly on the device at 25Hz. In each frame, we perform dense 6DoF tracking, which  continuously registers the RGB input to the incrementally built 3D model, minimizing a noise aware photoconsistency error metric. This  is followed by efficient key-frame selection, and dense per-frame stereo matching. These depth maps are fused volumetrically using  a method akin to KinectFusion, producing compelling surface models. For each frame, the implicit surface is extracted for live user  feedback and pose estimation. We demonstrate scans of a variety of objects, and compare to a Kinect-based baseline, showing on  average ∼ 1.5cm error. We qualitatively compare to a state of the art point-based mobile phone method, demonstrating an order of  magnitude faster scanning times, and fully connected surface models.  Index Terms—3D object scanning, surface reconstruction, mobile computing  Engel, J., Schöps, T., Cremers, D. (2014).  LSD-SLAM: Large-Scale Direct Monocular SLAM.  We propose a direct (feature-less) monocular SLAM algorithm which, in contrast to current state-of-the-art regarding direct methods, allows to build large-scale, consistent maps of the environment. Along with highly accurate pose estimation based on direct image alignment, the 3D environment is reconstructed in real-time as pose-graph of keyframes with associated semi-dense depth maps. These are obtained by filtering over a large number of pixelwise small-baseline stereo comparisons. The explicitly scale-drift aware formulation allows the approach to operate on challenging sequences including large variations in scene scale. Major enablers are two key novelties: (1) a novel direct tracking method which operates on , thereby explicitly detecting scale-drift, and (2) an elegant probabilistic solution to include the effect of noisy depth values into tracking. The resulting direct monocular SLAM system runs in real-time on a CPU.  J. Engel, V. Koltun and D. Cremers  "Direct Sparse Odometry,"  Direct Sparse Odometry (DSO) is a visual odometry method based on a novel, highly accurate sparse and direct structure and motion formulation. It combines a fully direct probabilistic model (minimizing a photometric error) with consistent, joint optimization of all model parameters, including geometry-represented as inverse depth in a reference frame-and camera motion. This is achieved in real time by omitting the smoothness prior used in other direct methods and instead sampling pixels evenly throughout the images. Since our method does not depend on keypoint detectors or descriptors, it can naturally sample pixels from across all image regions that have intensity gradient, including edges or smooth intensity variations on essentially featureless walls. The proposed model integrates a full photometric calibration, accounting for exposure time, lens vignetting, and non-linear response functions. We thoroughly evaluate our method on three different datasets comprising several hours of video. The experiments show that the presented approach significantly outperforms state-of-the-art direct and indirect methods in a variety of real-world settings, both in terms of tracking accuracy and robustness.  W. Liu et al.,  "TLIO: Tight Learned Inertial Odometry,"  2020  In this letter we propose a tightly-coupled Extended Kalman Filter framework for IMU-only state estimation. Strap-down IMU measurements provide relative state estimates based on IMU kinematic motion model. However the integration of measurements is sensitive to sensor bias and noise, causing significant drift within seconds. Recent research by Yan et al. (RoNIN) and Chen et al. (IONet) showed the capability of using trained neural networks to obtain accurate 2D displacement estimates from segments of IMU data and obtained good position estimates from concatenating them. This letter demonstrates a network that regresses 3D displacement estimates and its uncertainty, giving us the ability to tightly fuse the relative state measurement into a stochastic cloning EKF to solve for pose, velocity and sensor biases. We show that our network, trained with pedestrian data from a headset, can produce statistically consistent measurement and uncertainty to be used as the update step in the filter, and the tightly-coupled system outperforms velocity integration approaches in position estimates, and AHRS attitude filter in orientation estimates. Video materials and code can be found on our project page: http://cathias.github.io/TLIO/ .  K. Konolige, G. Grisetti, R. Kümmerle, W. Burgard, B. Limketkai and R. Vincent  "Efficient Sparse Pose Adjustment for 2D mapping,"  2010  Pose graphs have become a popular representation for solving the simultaneous localization and mapping (SLAM) problem. A pose graph is a set of robot poses connected by nonlinear constraints obtained from observations of features common to nearby poses. Optimizing large pose graphs has been a bottleneck for mobile robots, since the computation time of direct nonlinear optimization can grow cubically with the size of the graph. In this paper, we propose an efficient method for constructing and solving the linear subproblem, which is the bottleneck of these direct methods. We compare our method, called Sparse Pose Adjustment (SPA), with competing indirect methods, and show that it outperforms them in terms of convergence speed and accuracy. We demonstrate its effectiveness on a large set of indoor real-world maps, and a very large simulated dataset. Open-source implementations in C++, and the datasets, are publicly available.  S. Kohlbrecher, O. von Stryk, J. Meyer and U. Klingauf  "A flexible and scalable SLAM system with full 3D motion estimation,"  2011  For many applications in Urban Search and Rescue (USAR) scenarios robots need to learn a map of unknown environments. We present a system for fast online learning of occupancy grid maps requiring low computational resources. It combines a robust scan matching approach using a LIDAR system with a 3D attitude estimation system based on inertial sensing. By using a fast approximation of map gradients and a multi-resolution grid, reliable localization and mapping capabilities in a variety of challenging environments are realized. Multiple datasets showing the applicability in an embedded hand-held mapping system are provided. We show that the system is sufficiently accurate as to not require explicit loop closing techniques in the considered scenarios. The software is available as an open source package for ROS.  Z. Xuexi, L. Guokun, F. Genping, X. Dongliang and L. Shiliu  "SLAM Algorithm Analysis of Mobile Robot Based on Lidar," 2019  In this work, we tested Simultaneous localization and mapping (SLAM) about mobile robots in indoor environment, where all experiments were conducted based on the Robot Operating System (ROS). The urban search and rescue(USAR) environment was build in the ROS simulation tool Gazebo, and our car was used to test hector SLAM in Gazebo. The rplidar A1 single-line lidar was used for 2D laser scan matching data acquisition in the practical experiments and the indoor map was built by using the open source algorithms gmapping, karto SLAM, hector SLAM software package for indoor SLAM, which can get the indoor grid maps in ROS graphical tool RVIZ. The experimental results of the three open source algorithms show that the mobile robot for simultaneous localization and mapping (SLAM) is feasible, and high-precision grid maps can be constructed. Object modelling by registration of multiple range images Yang Chen, Gérard Medioni  keywords = {object modelling, 3D surface registration, range image registration}, abstract = {We study the problem of creating a complete model of a physical object. Although this may be possible using intensity images, we here use images which directly provide access to three dimensional information. The first problem that we need to solve is to find the transformation between the different views. Previous approaches either assume this transformation to be known (which is extremely difficult for a complete model), or compute it with feature matching (which is not accurate enough for integration). In this paper, we propose a new approach which works on range data directly and registers successive views with enough overlapping area to get an accurate transformation between views. This is performed by minimizing a functional which does not require point-to-point matches. We give the details of the registration method and modelling procedure and illustrate them on real range images of complex objects.}  X. Xu, L. Tian, J. Feng and J. Zhou  "OSRI: A Rotationally Invariant Binary Descriptor,"  2014  Binary descriptors are becoming widely used in computer vision field because of their high matching efficiency and low memory requirements. Since conventional approaches, which first compute a floating-point descriptor then binarize it, are computationally expensive, some recent efforts have focused on directly computing binary descriptors from local image patches. Although these binary descriptors enable a significant speedup in processing time, their performances usually drop a lot due to orientation estimation errors and limited description abilities. To address these issues, we propose a novel binary descriptor based on the ordinal and spatial information of regional invariants (OSRIs) over a rotation invariant sampling pattern. Our main contributions are twofold: 1) each bit in OSRI is computed based on difference tests of regional invariants over pairwise sampling-regions instead of difference tests of pixel intensities commonly used in existing binary descriptors, which can significantly enhance the discriminative ability and 2) rotation and illumination changes are handled well by ordering pixels according to their intensities and gradient orientations, meanwhile, which is also more reliable than those methods that resort to a reference orientation for rotation invariance. Besides, a statistical analysis of discriminative abilities of different parts in the descriptor is conducted to design a cascade filter which can reject nonmatching descriptors at early stages by comparing just a small portion of the whole descriptor, further reducing the matching time. Extensive experiments on four challenging data sets (Oxford, 53 Objects, ZuBuD, and Kentucky) show that OSRI significantly outperforms two state-of-the-art binary descriptors (FREAK and ORB). The matching performance of OSRI with only 512 bits is also better than the well-known floating-point descriptor SIFT (4K bits) and is comparable with the state-of-the-art floating-point descriptor MROGH (6K bits), while it is two orders of magnitude faster to match than SIFT and MROGH.  M. Kaess, A. Ranganathan and F. Dellaert  "iSAM: Incremental Smoothing and Mapping,"  2008  In this paper, we present incremental smoothing and mapping (iSAM), which is a novel approach to the simultaneous localization and mapping problem that is based on fast incremental matrix factorization. iSAM provides an efficient and exact solution by updating a QR factorization of the naturally sparse smoothing information matrix, thereby recalculating only those matrix entries that actually change. iSAM is efficient even for robot trajectories with many loops as it avoids unnecessary fill-in in the factor matrix by periodic variable reordering. Also, to enable data association in real time, we provide efficient algorithms to access the estimation uncertainties of interest based on the factored information matrix. We systematically evaluate the different components of iSAM as well as the overall algorithm using various simulated and real-world datasets for both landmark and pose-only settings.  M. J. Milford and G. F. Wyeth  "SeqSLAM: Visual route-based navigation for sunny summer days and stormy winter nights,"  2012  Learning and then recognizing a route, whether travelled during the day or at night, in clear or inclement weather, and in summer or winter is a challenging task for state of the art algorithms in computer vision and robotics. In this paper, we present a new approach to visual navigation under changing conditions dubbed SeqSLAM. Instead of calculating the single location most likely given a current image, our approach calculates the best candidate matching location within every local navigation sequence. Localization is then achieved by recognizing coherent sequences of these “local best matches”. This approach removes the need for global matching performance by the vision front-end - instead it must only pick the best match within any short sequence of images. The approach is applicable over environment changes that render traditional feature-based techniques ineffective. Using two car-mounted camera datasets we demonstrate the effectiveness of the algorithm and compare it to one of the most successful feature-based SLAM algorithms, FAB-MAP. The perceptual change in the datasets is extreme; repeated traverses through environments during the day and then in the middle of the night, at times separated by months or years and in opposite seasons, and in clear weather and extremely heavy rain. While the feature-based method fails, the sequence-based algorithm is able to match trajectory segments at 100% precision with recall rates of up to 60%.  R. A. Newcombe et al.  Newcombe, Richard A. and Izadi, Shahram and Hilliges, Otmar and Molyneaux, David and Kim, David and Davison, Andrew J. and Kohi, Pushmeet and Shotton, Jamie and Hodges, Steve and Fitzgibbon, Andrew  "KinectFusion: Real-time dense surface mapping and tracking,"  2011  We present a system for accurate real-time mapping of complex and arbitrary indoor scenes in variable lighting conditions, using only a moving low-cost depth camera and commodity graphics hardware. We fuse all of the depth data streamed from a Kinect sensor into a single global implicit surface model of the observed scene in real-time. The current sensor pose is simultaneously obtained by tracking the live depth frame relative to the global model using a coarse-to-fine iterative closest point (ICP) algorithm, which uses all of the observed depth data available. We demonstrate the advantages of tracking against the growing full surface model compared with frame-to-frame tracking, obtaining tracking and mapping results in constant time within room sized scenes with limited drift and high accuracy. We also show both qualitative and quantitative results relating to various aspects of our tracking and mapping system. Modelling of natural scenes, in real-time with only commodity sensor and GPU hardware, promises an exciting step forward in augmented reality (AR), in particular, it allows dense surfaces to be reconstructed in real-time, with a level of detail and robustness beyond any solution yet presented using passive computer vision.  Rossi et al  Real-Time Underwater StereoFusion  Many current and future applications of underwater robotics require real-time sensing and interpretation of the environment. As the vast majority of robots are equipped with cameras, computer vision is playing an increasingly important role it this field. This paper presents the implementation and experimental results of underwater StereoFusion, an algorithm for real-time 3D dense reconstruction and camera tracking. Unlike KinectFusion on which it is based, StereoFusion relies on a stereo camera as its main sensor. The algorithm uses the depth map obtained from the stereo camera to incrementally build a volumetric 3D model of the environment, while simultaneously using the model for camera tracking. It has been successfully tested both in a lake and in the ocean, using two different state-of-the-art underwater Remotely Operated Vehicles (ROVs). Ongoing work focuses on applying the same algorithm to acoustic sensors, and on the implementation of a vision based monocular system with the same capabilities.  [stereo](https://www.mdpi.com/search?q=stereo); [underwater](https://www.mdpi.com/search?q=underwater); [ROV](https://www.mdpi.com/search?q=ROV); [GPU](https://www.mdpi.com/search?q=GPU); [real-time](https://www.mdpi.com/search?q=real-time); [3D](https://www.mdpi.com/search?q=3D); [fusion](https://www.mdpi.com/search?q=fusion); [camera](https://www.mdpi.com/search?q=camera); [tracking](https://www.mdpi.com/search?q=tracking); [vision](https://www.mdpi.com/search?q=vision)[e](https://www.mdpi.com/search?q=stereo)  Salas-Moreno et al.  Slam++: Simultaneous localisation and mapping at the level of objects  We present the major advantages of a new'object oriented'3D SLAM paradigm, which takes full advantage in the loop of prior knowledge that many scenes consist of repeated, domain-specific objects and structures. As a hand-held depth camera browses a cluttered scene, realtime 3D object recognition and tracking provides 6DoF camera-object constraints which feed into an explicit graph of objects, continually refined by efficient pose-graph optimisation. This offers the descriptive and predictive power of SLAM systems which perform dense surface reconstruction, but with a huge representation compression. The object graph enables predictions for accurate ICP-based camera to model tracking at each live frame, and efficient active search for new objects in currently undescribed image regions. We demonstrate real-time incremental SLAM in large, cluttered environments, including loop closure, relocalisation and the detection of moved objects, and of course the generation of an object level scene description with the potential to enable interaction. BatSLAM: Simultaneous Localization and Mapping Using Biomimetic Sonar Jan Steckel , Herbert Peremans  We propose to combine a biomimetic navigation model which solves a simultaneous localization and mapping task with a biomimetic sonar mounted on a mobile robot to address two related questions. First, can robotic sonar sensing lead to intelligent interactions with complex environments? Second, can we model sonar based spatial orientation and the construction of spatial maps by bats? To address these questions we adapt the mapping module of RatSLAM, a previously published navigation system based on computational models of the rodent hippocampus. We analyze the performance of the proposed robotic implementation operating in the real world. We conclude that the biomimetic navigation model operating on the information from the biomimetic sonar allows an autonomous agent to map unmodified (office) environments efficiently and consistently. Furthermore, these results also show that successful navigation does not require the readings of the biomimetic sonar to be interpreted in terms of individual objects/landmarks in the environment. We argue that the system has applications in robotics as well as in the field of biology as a simple, first order, model for sonar based spatial orientation and map building.  *ElasticFusion: Dense SLAM without a pose graph*.  Whelan, T., Leutenegger, S., Salas-Moreno, R., Glocker, B., & Davison, A.  (2015)  Abstract—We present a novel approach to real-time dense  visual SLAM. Our system is capable of capturing comprehensive  dense globally consistent surfel-based maps of room scale envi-  ronments explored using an RGB-D camera in an incremental  online fashion, without pose graph optimisation or any post-  processing steps. This is accomplished by using dense frame-to-  model camera tracking and windowed surfel-based fusion cou-  pled with frequent model refinement through non-rigid surface  deformations. Our approach applies local model-to-model surface  loop closure optimisations as often as possible to stay close to the  mode of the map distribution, while utilising global loop closure  to recover from arbitrary drift and maintain global consistency.  I. INTRODUCTION  In dense 3D SLAM, a space is mapped by fusing the data  from a moving sensor into a representation of the continuous  surfaces it contains, permitting accurate viewpoint-invariant  localisation as well as offering the potential for detailed  semantic scene understanding. However, existing dense SLAM  methods suitable for incremental, real-time operation struggle  when the sensor makes movements which are both of extended  duration and often criss-cross loop back on themselves. Such  a trajectory is typical if a non-expert person with a handheld  depth camera were to scan in a room with a loopy “painting”  motion; or would also be characteristic of a robot aiming to  explore and densely map an unknown environment.  M. Keller, D. Lefloch, M. Lambers, S. Izadi, T. Weyrich and A. Kolb  "Real-Time 3D Reconstruction in Dynamic Scenes Using Point-Based Fusion,"  2013  Real-time or online 3D reconstruction has wide applicability and receives further interest due to availability of consumer depth cameras. Typical approaches use a moving sensor to accumulate depth measurements into a single model which is continuously refined. Designing such systems is an intricate balance between reconstruction quality, speed, spatial scale, and scene assumptions. Existing online methods either trade scale to achieve higher quality reconstructions of small objects/scenes. Or handle larger scenes by trading real-time performance and/or quality, or by limiting the bounds of the active reconstruction. Additionally, many systems assume a static scene, and cannot robustly handle scene motion or reconstructions that evolve to reflect scene changes. We address these limitations with a new system for real-time dense reconstruction with equivalent quality to existing online methods, but with support for additional spatial scale and robustness in dynamic scenes. Our system is designed around a simple and flat point-Based representation, which directly works with the input acquired from range/depth sensors, without the overhead of converting between representations. The use of points enables speed and memory efficiency, directly leveraging the standard graphics pipeline for all central operations, i.e., camera pose estimation, data association, outlier removal, fusion of depth maps into a single denoised model, and detection and update of dynamic objects. We conclude with qualitative and quantitative results that highlight robust tracking and high quality reconstructions of a diverse set of scenes at varying scales.  McCormac, B. J. (2018).  *SLAM and deep learning for 3D indoor scene understanding.*  We build upon research in the fields of Simultaneous Localisation and Mapping (SLAM) and Deep Learning to develop 3D maps of indoor scenes that not only describe where things are but what they are. We focus on real-time online methods suitable for applications such as domestic robotics and augmented reality. While early approaches to SLAM used sparse feature maps for localisation, recent years have seen the advent of real-time dense SLAM systems which enabled applications not possible with only sparse feature maps. Further augmenting dense maps with semantic information will in future enable more intelligent domestic robots and more intuitive human-map interactions not possible with map geometry alone. Early work presented here sought to combine recent advances in semantic segmentation using Convolutional Neural Networks (CNNs) with dense SLAM approaches to produce a semantically annotated dense 3D map. Although we found this combination improved segmentation performance, its inherent limitations subsequently led to a paradigm shift away from semantic annotation towards instance detection and 3D object-level mapping. We propose a new type of SLAM system consisting of discovered object instances that are reconstructed online in individual volumes. We develop a new approach to robustly combine multiple associated 2D instance mask detections into a fused 3D foreground segmentation for each object. The use of individual volumes allows the relative poses of objects to be optimised in a pose-graph, producing a consistent global map that allows objects to be reused on loopy trajectories, and which can improve reconstruction quality. A notable feature of CNNs is their ability to make use of large annotated datasets, and so we also explore methods to reduce the cost of indoor semantic dataset production. We explore SLAM as a means of mitigating labour intensive annotation of video data, but found that producing a large-scale dataset with such an approach would still require significant resources. We therefore explore automated methods to produce a large-scale photorealistic synthetic dataset of indoor trajectories at low cost, and we verify the benefits of the dataset on the task of semantic segmentation. To automate trajectory generation we present a novel two-body random trajectory method that mitigates issues of a completely random approach, and which has subsequently been used in other synthetic indoor datasets.  A Survey on Active Simultaneous Localization and  Mapping: State of the Art and New Frontiers  SLAM, however, is a passive method and is not concerned  with guiding the navigation process. In contrast, *active* approaches  do consider the navigation aspects of the problem.  Bajcsy [6], Cowan andKovesi [7], and Aloimonos et al. [8] were  the first to study and analyze the problem of active perception  (also referred to as active information acquisition [9]) in the late  1990s. Bajcsy [10] would later formally define it as the problem  of actively acquiring data in order to achieve a certain goal,  necessarily involving a decision-making process. For the cases in  which the objective is to improve localization, mapping, or both,  the problems are, respectively, referred to as active localization,  active mapping, and active SLAM.  *Active mapping* was the first problem to be addressed, dating  back to the work of Connolly [11] in 1985. Better known since  then as the *next best view* problem, active mapping tackles the  search of the optimal movements to create the best possible  representation of an environment. Subsequent examples date  to the 1990s [12], [13], [14], always under the assumption of  perfectly known sensor localization. This problem has been  primarily addressed in the computer vision community to reconstruct  objects and scenes from multiple viewpoints, since  the nature of the projective geometry for monocular cameras,  occlusions, and limited field of view often make impossible to  do it from just one viewpoint; see [15] and the references therein.  In a similar vein, *active localization* aims to improve the  estimation of the robot’s pose by determining how it should  move, assuming the map of the environment is known. First  relevant works can be traced back to 1998, when Fox et al. [16]  and Borgi and Caglioti [17] formulated it as the problem of determining  the robot motion so as to minimize its future expected  (i.e., a posteriori) uncertainty. In particular, it is in [16] where  the foundations of the current workflow were laid:  1) goal identification;  2) utility computation;  3) action selection (we will extensively review these stages  later in this survey).  S. Thrun, W. Burgard, and D. Fox,  *Probabilistic Robotics* (Intelligent  Robotics and Autonomous Agents).  S. Thrun, W. Burgard, and D. Fox, *Probabilistic Robotics* (Intelligent  Robotics and Autonomous Agents). Cambridge, MA, USA: MIT Press,  2005.  Probabilistic robotics is a new and growing area in robotics, concerned with perception and control in the face of uncertainty. Building on the field of mathematical statistics, probabilistic robotics endows robots with a new level of robustness in real-world situations. This book introduces the reader to a wealth of techniques and algorithms in the field. All algorithms are based on a single overarching mathematical foundation. Each chapter provides example implementations in pseudo code, detailed mathematical derivations, discussions from a practitioner's perspective, and extensive lists of exercises and class projects. The book's Web site, www.probabilistic-robotics.org, has additional material. The book is relevant for anyone involved in robotic software development and scientific research. It will also be of interest to applied statisticians and engineers dealing with real-world sensor data.  D. Fox,W. Burgard, and S.Thrun  “Active Markov localization for mobile  robots,”  1998  Localization is the problem of determining the position of a mobile robot from sensor data. Most existing localization approaches are passive, i.e., they do not exploit the opportunity to control the robot's effectors during localization. This paper proposes an active localization approach. The approach is based on Markov localization and provides rational criteria for (1) setting the robot's motion direction (exploration), and (2) determining the pointing direction of the sensors so as to most efficiently localize the robot. Furthermore, it is able to deal with noisy sensors and approximative world models. The appropriateness of our approach is demonstrated empirically using a mobile robot in a structured office environment.  G. Borghi and V. Caglioti  "Minimum uncertainty explorations in the self-localization of mobile robots,"  1998  The self-localization of a mobile robot within a known environment, by means of an orientable range finder, is considered. The problem of the determination of the sensor orientation which minimizes the position uncertainty of the mobile robot is addressed. An efficient technique is proposed to determine the optimal sensor exploration, given the current robot position estimate and its uncertainty. Once a tentative exploration is given, the technique avoids to take any worst exploration into account, allowing to efficiently determine the optimal one. Both location accuracy and efficiency have been analyzed in the paper. The time needed to plan the exploration is found to be well below the time needed for the sensor activation. The technique is demonstrated by experimental results on environments containing curvilinear parts.  G. Grisetti, R. Kümmerle, C. Stachniss and W. Burgard  "A Tutorial on Graph-Based SLAM,"  2010  Being able to build a map of the environment and to simultaneously localize within this map is an essential skill for mobile robots navigating in unknown environments in absence of external referencing systems such as GPS. This so-called simultaneous localization and mapping (SLAM) problem has been one of the most popular research topics in mobile robotics for the last two decades and efficient approaches for solving this task have been proposed. One intuitive way of formulating SLAM is to use a graph whose nodes correspond to the poses of the robot at different points in time and whose edges represent constraints between the poses. The latter are obtained from observations of the environment or from movement actions carried out by the robot. Once such a graph is constructed, the map can be computed by finding the spatial configuration of the nodes that is mostly consistent with the measurements modeled by the edges. In this paper, we provide an introductory description to the graph-based SLAM problem. Furthermore, we discuss a state-of-the-art solution that is based on least-squares error minimization and exploits the structure of the SLAM problems during optimization. The goal of this tutorial is to enable the reader to implement the proposed methods from scratch.  C. Cadena et al.  "Past, Present, and Future of Simultaneous Localization and Mapping: Toward the Robust-Perception Age,"  2016  Simultaneous localization and mapping (SLAM) consists in the concurrent construction of a model of the environment (the map), and the estimation of the state of the robot moving within it. The SLAM community has made astonishing progress over the last 30 years, enabling large-scale real-world applications and witnessing a steady transition of this technology to industry. We survey the current state of SLAM and consider future directions. We start by presenting what is now the de-facto standard formulation for SLAM. We then review related work, covering a broad set of topics including robustness and scalability in long-term mapping, metric and semantic representations for mapping, theoretical performance guarantees, active SLAM and exploration, and other new frontiers. This paper simultaneously serves as a position paper and tutorial to those who are users of SLAM. By looking at the published research with a critical eye, we delineate open challenges and new research issues, that still deserve careful scientific investigation. The paper also contains the authors' take on two questions that often animate discussions during robotics conferences: Do robots need SLAM? and Is SLAM solved?  ACTIVE SLAM  R. Bajcsy  “Active perception vs. passive perception,”  1985.1087373  Most past and present work in machine perception has involved extensive static analysis of passively sampled data. However, it should be axiomatic that perception is not passive, but active. Furthermore, most past and current robotics research use rather rigid assumptions, models about the world, objects and their relationships. It is not so difficult to see that these assumptions, most of the time, in realistic situations do not hold, and hence, the robots do not perform to the designer’s expectations.  C. K. Cowan and P. D. Kovesi  “Automatic sensor placement from vision  task requirements,”  1988  The problem of automatically generating the possible camera locations for observing an object is defined, and an approach to its solution is presented. The approach, which uses models of the object and the camera, is based on meeting the requirements that: the spatial resolution be above a minimum value, all surface points be in focus, all surfaces lie within the sensor field of view and no surface points be occluded. The approach converts each sensing requirement into a geometric constraint on the sensor location, from which the three-dimensional region of viewpoints that satisfies that constraint is computed. The intersection of these regions is the space where a sensor may be located. The extension of this approach to laser-scanner range sensors is also described. Examples illustrate the resolution, focus, and field-of-view constraints for two vision tasks  Aloimonos, Yiannis, Bandyopadhyay  “Active vision.”  (2004)  We investigate several basic problems in vision under the assumption that the observer is active. An observer is called active when engaged in some kind of activity whose purpose is to control the geometric parameters of the sensory apparatus. The purpose of the activity is to manipulate the constraints underlying the observed phenomena in order to improve the quality of the perceptual results. For example a monocular observer that moves with a known or unknown motion or a binocular observer that can rotate his eyes and track environmental objects are just two examples of an observer that we call active. We prove that an active observer can solve basic vision problems in a much more efficient way than a passive one. Problems that are ill-posed and nonlinear for a passive observer become well-posed and linear for an active observer. In particular, the problems of shape from shading and depth computation, shape from contour, shape from texture, and structure from motion are shown to be much easier for an active observer than for a passive one. It has to be emphasized that correspondence is not used in our approach, i.e., active vision is not correspondence of features from multiple viewpoints. Finally, active vision here does not mean active sensing, and this paper introduces a general methodology, a general framework in which we believe low-level vision problems should be addressed.  N. Atanasov, J. Le Ny, K. Daniilidis, and G. Pappas  “Information  acquisition with sensing robots: Algorithms and error bounds,”  2014  Utilizing the capabilities of configurable sensing systems requires addressing difficult information gathering problems. Near-optimal approaches exist for sensing systems without internal states. However, when it comes to optimizing the trajectories of mobile sensors the solutions are often greedy and rarely provide performance guarantees. Notably, under linear Gaussian assumptions, the problem becomes deterministic and can be solved off-line. Approaches based on submodularity have been applied by ignoring the sensor dynamics and greedily selecting informative locations in the environment. This paper presents a non-greedy algorithm with suboptimality guarantees, which does not rely on submodularity and takes the sensor dynamics into account. Our method performs provably better than the widely used greedy one. Coupled with linearization and model predictive control, it can be used to generate adaptive policies for mobile sensors with non-linear sensing models. Applications in gas concentration mapping and target tracking are presented.  R. Bajcsy  “Active perception”  1988  Active perception (active vision specifically) is defined as a study of modeling and control strategies for perception. Local methods are distinguished from global models by their extent of application in space and time. The local models represent procedures and parameters such as optical distortions of the lens, focal lens, spatial resolution, bandpass filter, etc, The global models, on the other hand, characterize the overall performance and make predictions on how the individual modules interact. The control strategies are formulated as a search of such sequences of steps that would minimize a loss function while still seeking the most information. Examples are shown as the existence proof of the proposed theory on obtaining range from focus and stereo/vergence on 2-D segmentation of an image and 3-D shape parameterization.  MULTIPLE VIEWPOINTS ACTIVE MAPPING  C. Connolly  “The determination of next best views”  1985  There are situations in which one would like to know a good sequence of range-image views for obtaining a complete model of a scene. This paper describes two algorithms which use partial octree models to determine the "best" next view to take.  J. Maver and R. Bajcsy  “Occlusions as a guide for planning the  next view”  1993  A strategy for acquiring 3-D data of an unknown scene, using range images obtained by a light stripe range finder is addressed. The foci of attention are occluded regions, i.e., only the scene at the borders of the occlusions is modeled to compute the next move. Since the system has knowledge of the sensor geometry, it can resolve the appearance of occlusions by analyzing them. The problem of 3-D data acquisition is divided into two subproblems due to two types of occlusions. An occlusion arises either when the reflected laser light does not reach the camera or when the directed laser light does not reach the scene surface. After taking the range image of a scene, the regions of no data due to the first kind of occlusion are extracted. The missing data are acquired by rotating the sensor system in the scanning plane, which is defined by the first scan. After a complete image of the surface illuminated from the first scanning plane has been built, the regions of missing data due to the second kind of occlusions are located. Then, the directions of the next scanning planes for further 3-D data acquisition are computed.  P. Whaite and F. P. Ferrie  “Autonomous exploration: Driven by uncertainty”  1997  R. Pito  "A solution to the next best view problem for automated surface acquisition"  1999  A solution to the "next best view" (NBV) problem for automated surface acquisition is presented. The NBV problem is to determine which areas of a scanner's viewing volume need to be scanned to sample all of the visible surfaces of an a priori unknown object and where to position/control the scanner to sample them. A method for determining the unscanned areas of the viewing volume is presented. In addition, a novel representation, positional space, is presented which facilitates a solution to the NBV problem by representing what must be and what can be scanned in a single data structure. The number of costly computations needed to determine if an area of the viewing volume would be occluded from some scanning position is decoupled from the number of positions considered for the NBV, thus reducing the computational cost of choosing one. An automated surface acquisition systems designed to scan all visible surfaces of an a priori unknown object is demonstrated on real objects.  F. Zeng, C. Wang, and S. S. Ge  “A survey on visual navigation for  artificial agents with deep reinforcement learning”  2020  Visual navigation (vNavigation) is a key and fundamental technology for artificial agents’ interaction with the environment to achieve advanced behaviors. Visual navigation for artificial agents with deep reinforcement learning (DRL) is a new research hotspot in artificial intelligence and robotics that incorporates the decision making of DRL into visual navigation. Visual navigation via DRL, an end-to-end method, directly receives the high-dimensional images and generates an optimal navigation policy. In this paper, we first present an overview on reinforcement learning (RL), deep learning (DL) and deep reinforcement learning (DRL). Then, we systematically describe five main categories of visual DRL navigation: direct DRL vNavigation, hierarchical DRL vNavigation, multi-task DRL vNavigation, memory-inference DRL vNavigation and vision-language DRL vNavigation. These visual DRL navigation algorithms are reviewed in detail. Finally, we discuss the challenges and some possible opportunities to visual DRL navigation for artificial agents.  ACTIVE LOCALOSATION  D. Fox,W. Burgard, and S.Thrun  “Active Markov localization for mobile  robots,”  1998  Localization is the problem of determining the position of a mobile robot from sensor data. Most existing localization approaches are passive, i.e., they do not exploit the opportunity to control the robot's effectors during localization. This paper proposes an active localization approach. The approach is based on Markov localization and provides rational criteria for (1) setting the robot's motion direction (exploration), and (2) determining the pointing direction of the sensors so as to most efficiently localize the robot. Furthermore, it is able to deal with noisy sensors and approximative world models. The appropriateness of our approach is demonstrated empirically using a mobile robot in a structured office environment.  G. Borghi and V. Caglioti  "Minimum uncertainty explorations in the self-localization of mobile robots,"  1998  The self-localization of a mobile robot within a known environment, by means of an orientable range finder, is considered. The problem of the determination of the sensor orientation which minimizes the position uncertainty of the mobile robot is addressed. An efficient technique is proposed to determine the optimal sensor exploration, given the current robot position estimate and its uncertainty. Once a tentative exploration is given, the technique avoids to take any worst exploration into account, allowing to efficiently determine the optimal one. Both location accuracy and efficiency have been analyzed in the paper. The time needed to plan the exploration is found to be well below the time needed for the sensor activation. The technique is demonstrated by experimental results on environments containing curvilinear parts.  H. Carrillo, I. Reid, and J. A. Castellanos,  “On the comparison of  uncertainty criteria for active SLAM,”  2012  In this paper, we consider the computation of the D-optimality criterion as a metric for the uncertainty of a SLAM system. Properties regarding the use of this uncertainty criterion in the active SLAM context are highlighted, and comparisons against the A-optimality criterion and entropy are presented. This paper shows that contrary to what has been previously reported, the D-optimality criterion is indeed capable of giving fruitful information as a metric for the uncertainty of a robot performing SLAM. Finally, through various experiments with simulated and real robots, we support our claims and show that the use of D-opt has desirable effects in various SLAM related tasks such as active mapping and exploration.  A. J. Davison and D. W. Murray,  “Simultaneous localization and mapbuilding  using active vision,”  2002  An active approach to sensing can provide the focused measurement capability over a wide field of view which allows correctly formulated simultaneous localization and map-building (SLAM) to be implemented with vision, permitting repeatable longterm localization using only naturally occurring, automatically-detected features. In this paper, we present the first example of a general system for autonomous localization using active vision, enabled here by a high-performance stereo head, addressing such issues as uncertainty-based measurement selection, automatic map-maintenance, and goal-directed steering. We present varied real-time experiments in a complex environment.  S. B. Thrun and K. Möller,  “Active exploration in dynamic environments,”  1991  Whenever an agent learns to control an unknown environment, two opposing principles have to be combined, namely: *exploration* (long-term optimization) and *exploitation* (short-term optimization). Many real-valued connectionist approaches to learning control realize exploration by randomness in action selection. This might be disadvantageous when costs are assigned to "negative experiences". The basic idea presented in this paper is to make an agent explore unknown regions in a more directed manner. This is achieved by a so-called *competence map*, which is trained to predict the controller's accuracy, and is used for guiding exploration. Based on this, a bistable system enables smoothly switching attention between two behaviors - exploration and exploitation - depending on expected costs and knowledge gain.  The appropriateness of this method is demonstrated by a simple robot navigation task. |

Section 3 describes different types of sensors utilized in the SLAM approaches alongwith shortcomings. Section 4 presents a review of feature extraction and matching algorithms with simulation results. Sensor fusion is discussed in Section 5 Deep Learning (DL) methods and V-SLAM datasets are studied in a comparison view in Sections 6 and 7,