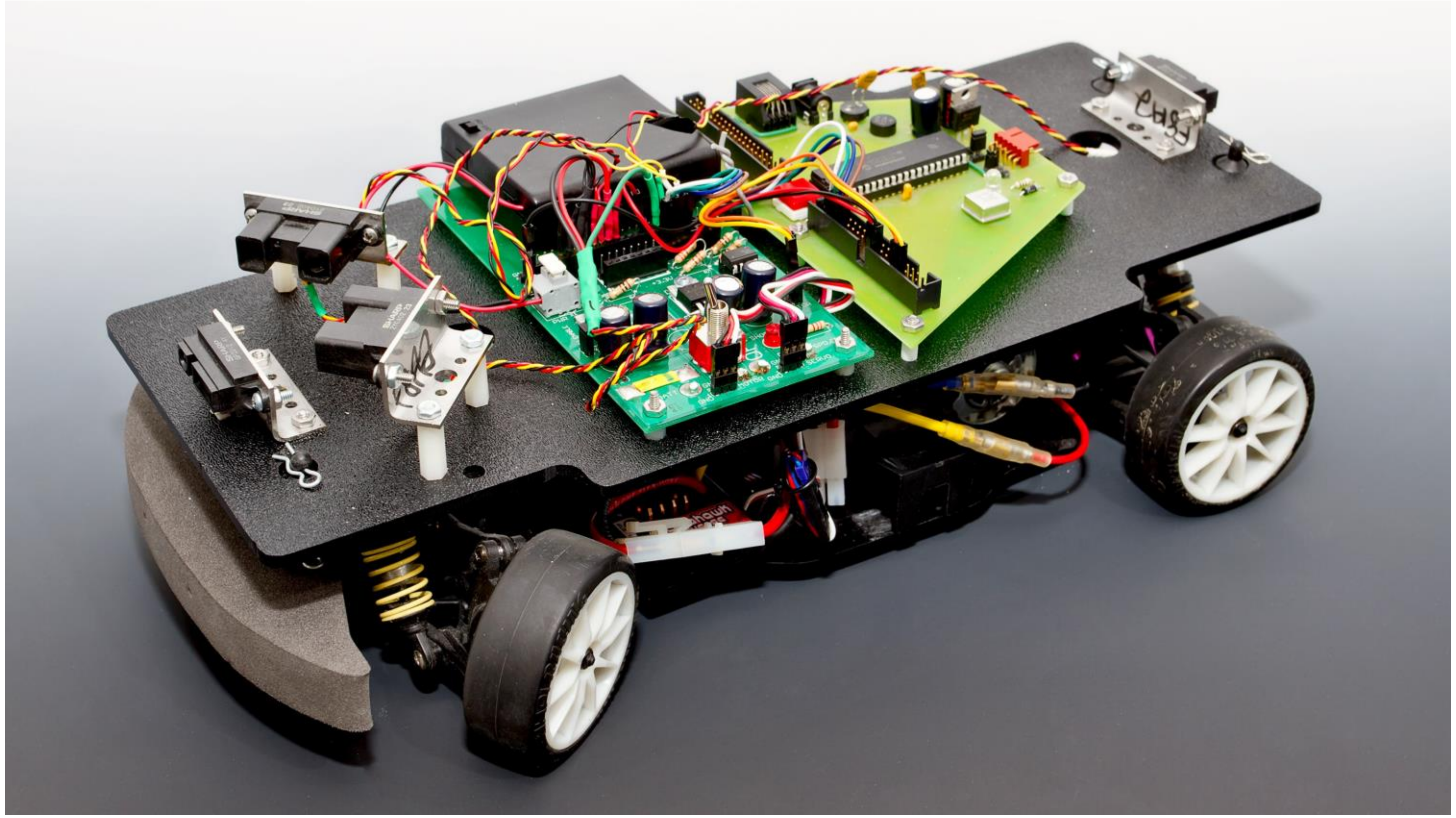
SLAM

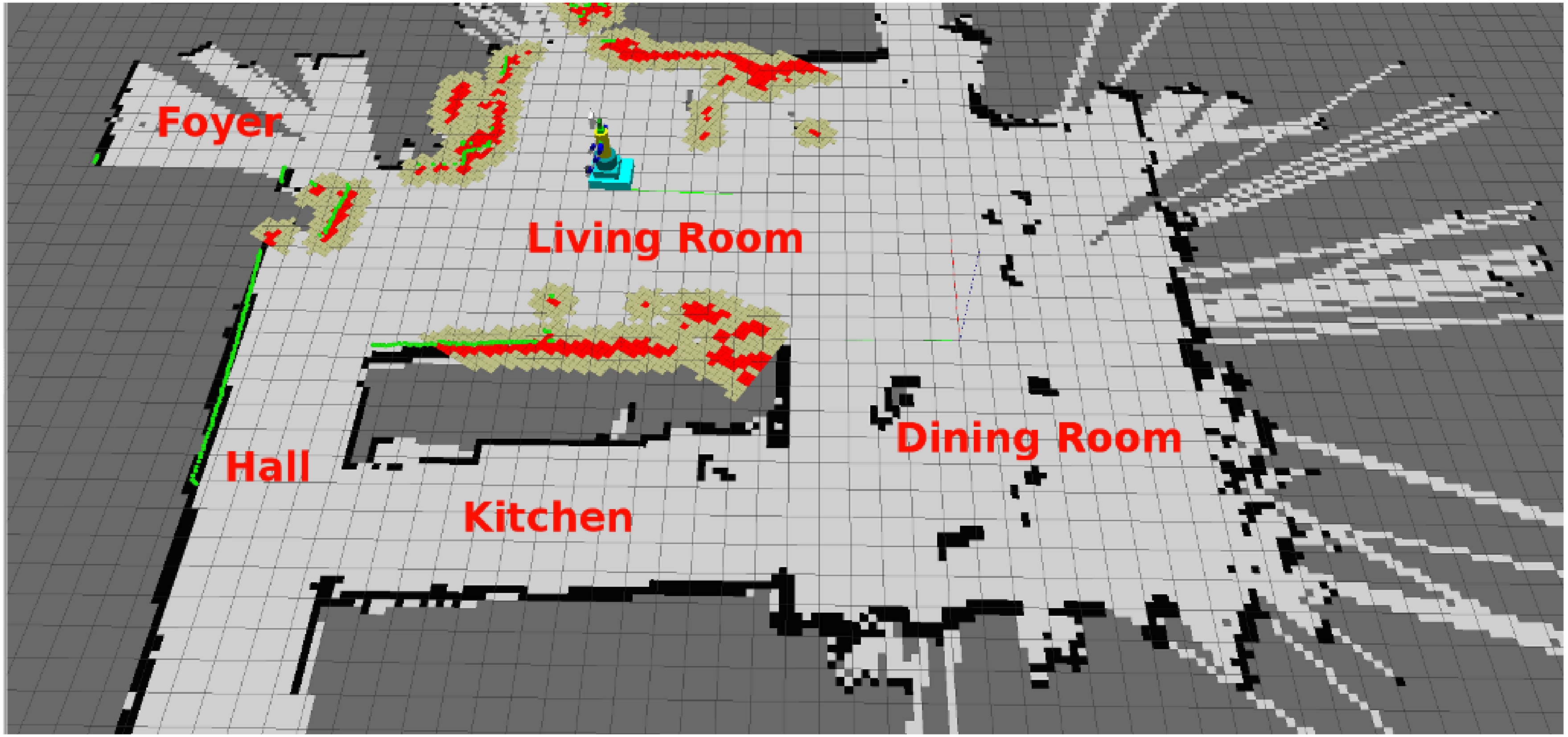
SLAM Concepts: Important terminologies

- **Robot**: A device that moves through the environment



SLAM Concepts: Important terminologies

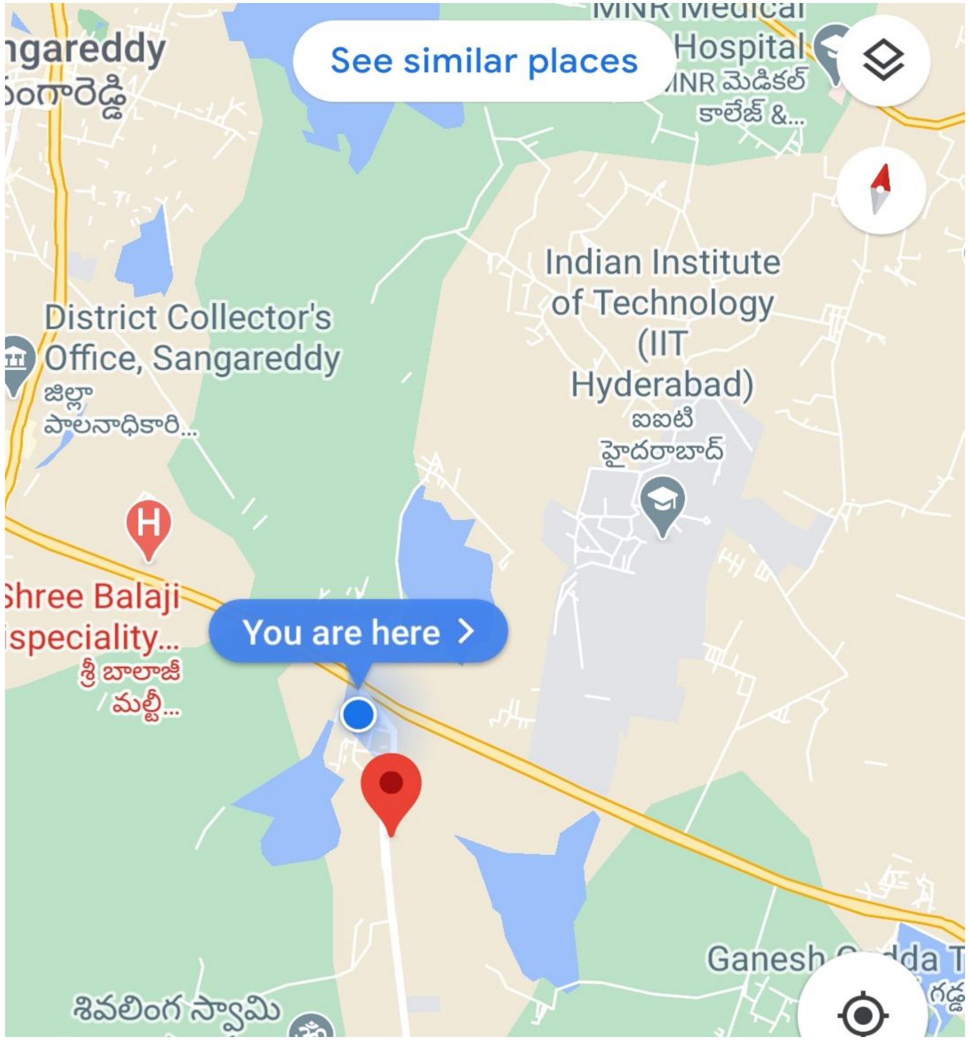
- **Mapping**: Modelling the environment



Source: https://www.sifsof.com/clinical-apps/simultaneous-localization-and-mapping-slam/

SLAM Concepts: Important terminologies

- **State estimation**: current state e.g. location, velocity
- **Localization**: Part of state estimation e.g. find location of robot



SLAM Concepts: Important terminologies

- **SLAM** (Simultaneous Localization and Mapping): Simultaneously finding location of robot and map the environment
- Navigation is the motivation for SLAM
- **Motion planning:** Plan the motion of a robot

SLAM

- Computing the robot’s poses and map the environment at the same time
- Localization-estimating robot’s location
- Mapping-building a map
- SLAM: building a map and localize the robot simultaneously
- Application examples: underground mines vacuum cleaner

History

- 1986 IEEE Robotics and Automation Conference held in San Francisco, California: recognition that consistent **probabilistic mapping was a fundamental problem in robotics** with major conceptual and computational issues that needed to be addressed
- Work by Smith and Cheesman [2], 1987 and Durrant-Whyte [1], 1988 established a statistical basis for **describing relationships between landmarks and manipulating geometric uncertainty**
- A key element of this work was to show that there must be a **high degree of correlation between estimates of the location of different landmarks in a map and that**, indeed, these correlations would grow with successive observations.

History

- 1990: the landmark paper by Smith et al. [3]: This paper showed that as a mobile robot moves through an unknown environment taking relative observations of landmarks, the **estimates of these landmarks are all necessarily correlated with each other because of the common error** in estimated vehicle location [4]
    - ➢A consistent full solution to the combined localization and mapping problem would **require a joint state composed of the vehicle pose and every landmark position**, to be updated following each landmark observation
    - ➢ In turn, this would require the estimator to employ a huge state vector (on the order of the number of landmarks maintained in the map) with computation scaling as the square of the number of landmarks.

Courtsey: [3] R. Smith, M. Self, and P. Cheeseman, "Estimating uncertain spatial relationships in robotics," in *Autonomous Robot Vehicles,* I.J. Cox and G.T. Wilfon, Eds. New York: Springer-Verlag, pp. 167–193, 1990.
[4] J.J. Leonard and H.F. Durrant-Whyte, "Simultaneous map building and localisation for an autonomous mobile robot," in Proc. IEEE Int. Workshop Intell. Robots Syst. (IROS), Osaka, Japan, 1991, pp. 1442–1447.

History

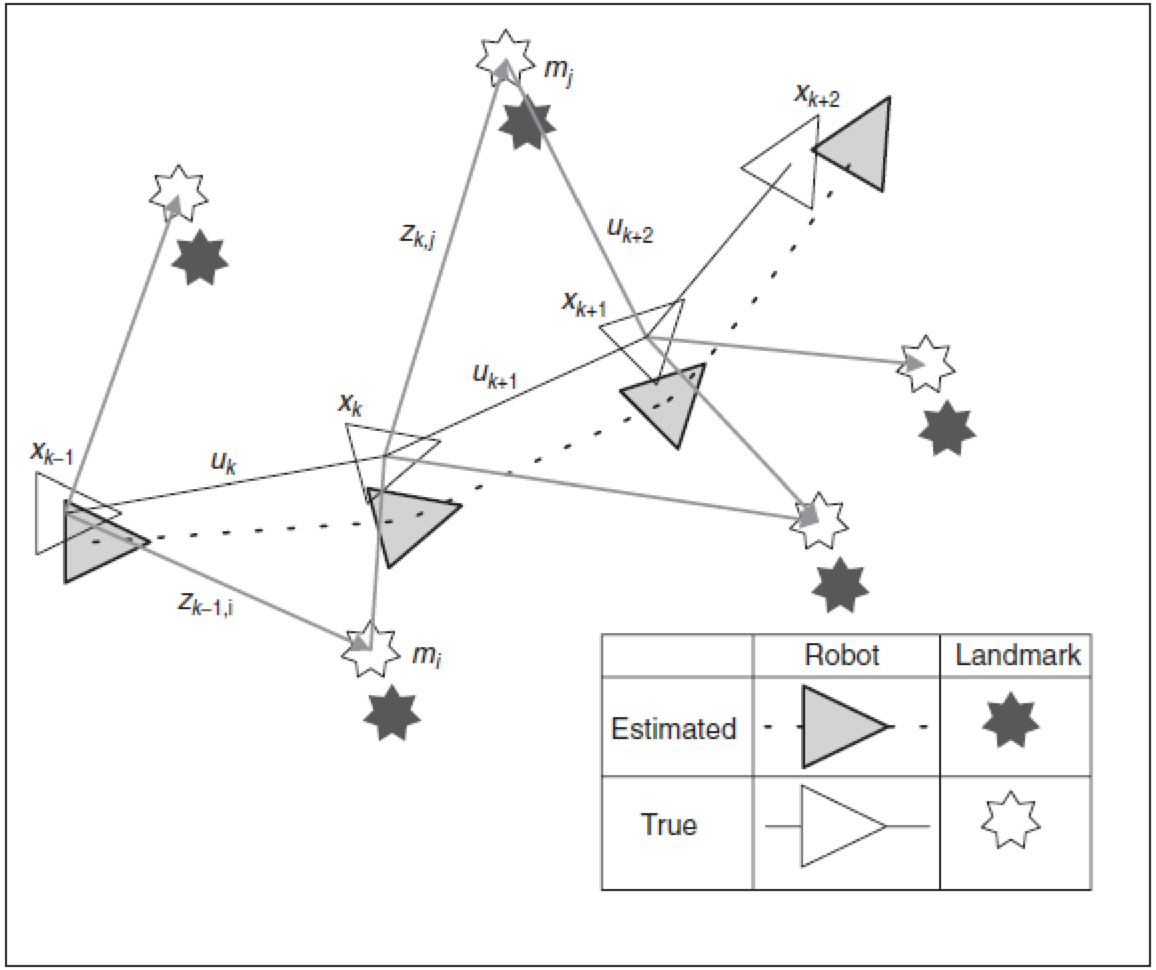
- Temporary Halt: Assumption that the estimated map errors would not converge and would instead exhibit a random-walk behavior with unbounded error growth
- 1995: The structure of the SLAM problem, the convergence result and the **coining of the acronym SLAM** was first presented in a mobile robotics survey paper presented at the 1995 International Symposium on Robotics Research [5]
- 1996-97: The essential theory on convergence and many of the initial results were developed by Csorba [6,7]

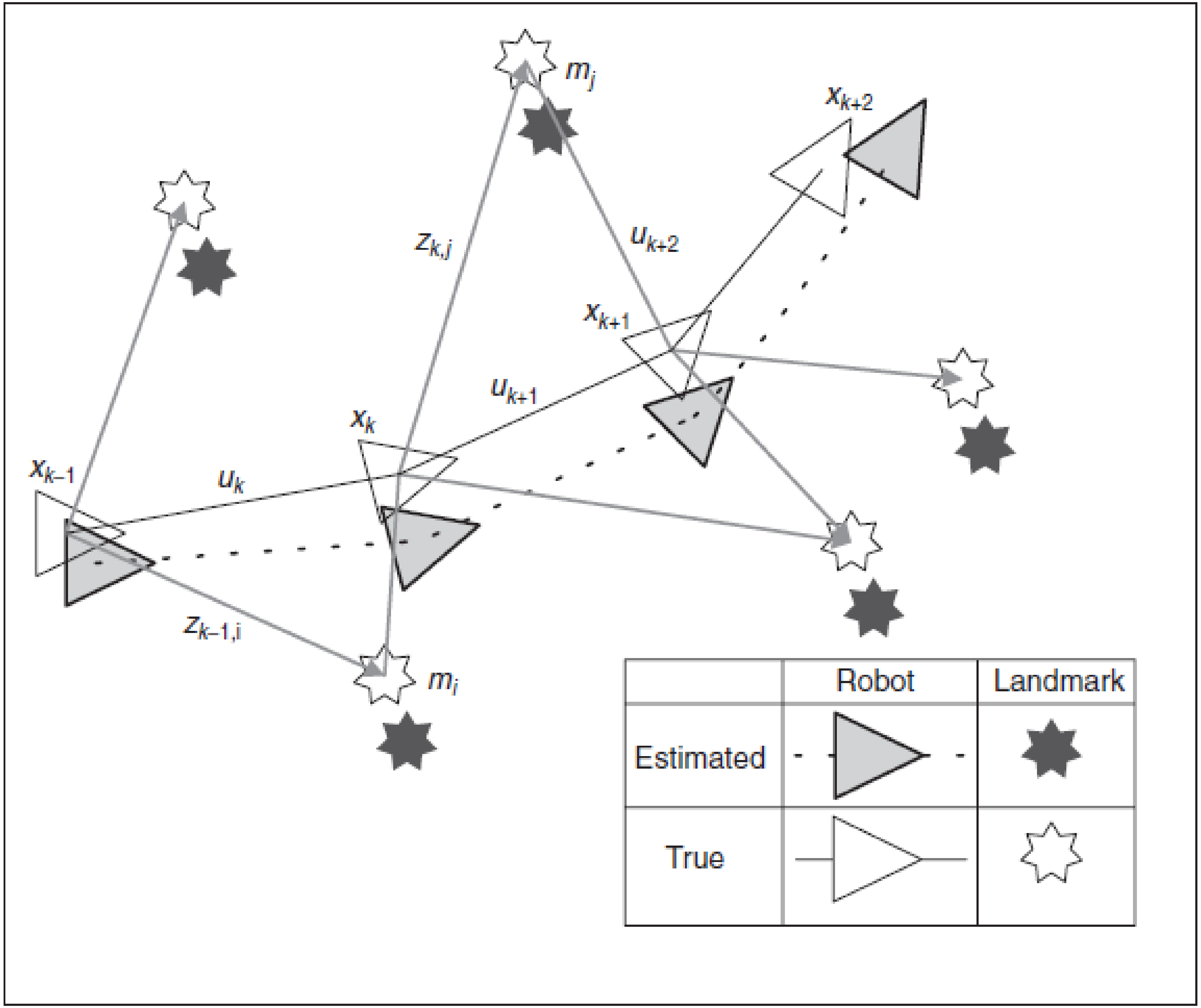
History

- 1999, International Symposium on Robotics Research (ISRR'99) [23] was an important meeting point where the first SLAM session was held and where a degree of convergence between the Kalman-filter-based SLAM methods and the probabilistic localization and mapping methods **introduced by Thrun [42]** was achieved.
- 2000 IEEE International Conference on Robotics and Automation (ICRA) Workshop on SLAM attracted 15 researchers and focused on issues such as algorithmic complexity, data association, and implementation challenges.
- The following SLAM workshop at the 2002 ICRA attracted 150 researchers with a broad range of interests and applications.
- The 2002 SLAM summer school hosted by Henrik Christiansen at KTH in Stockholm attracted all the key researchers together with some 50 Ph.D. students from around the world and was a tremendous success in building the field.
- The SLAM summer school ran in 2004 in Toulouse and will run at Oxford, England, in 2006.

Formulation and Structure of the SLAM Problem

- Consider a mobile robot moving through an environment taking relative observations of a number of unknown landmarks using a sensor mounted on the robot
- x_k: the state vector describing the location and orientation of the vehicle
- u_k : the control vector, applied at time k − 1 to drive the vehicle to a state x_k at time k





m_j
x_{k+2}
$z_{k,j}$
u_{k+2}
x_{k+1}
u_{k+1}
x_k
x_{k-1}
u_k
$z_{k-1,i}$
m_i
Robot
Landmark
Estimated
True

- m_i: a vector describing the location of the ith landmark whose true location is assumed time invariant
- z_{ik} : an observation taken from the vehicle of the location of the ith landmark at time k
- $X_{0:k}$ = $\{x_0, x_1, \cdots, x_k\}$= $\{X_{0:k-1}, x_k\}$: history of vehicle location
- $U_{0:k}$ = $\{u_1, u_2, \cdots, u_k\}$= $\{U_{0:k-1}, u_k\}$: the history of control inputs
- $\boldsymbol{m}$ = $\{m_1, m_2, \cdots, m_n\}$= the set of all landmarks
- $Z_{0:k}$ = $\{z_1, z_2, \cdots, z_k\}$= $\{Z_{0:k-1}, z_k\}$: the set of all landmark observations.

SLAM problem definition

- Given: Robot's control e.g. left, right etc.

$$u_{0:k} = \{u_1, u_2, \ldots\ldots\ldots u_k\}$$

- Observation: $z_{0:k} = \{z_1, z_2, \ldots\ldots z_k\}$
- Wanted: map of the environment 'm'
- Path of the robot $x_{0:k} = \{x_0, x_1, \ldots x_k\}$
- here starting point: x_0

Probabilistic SLAM

- Use prob. Theory to explicitly represent the uncertainty
- In other words, estimate robot's path and map given observation and control
- The map and the path instead of being precise is represented by probability distribution, represented as:
- $P(x_k, m | Z_{0:k}, U_{0:k}, x_0)$: joint posterior density of the landmark locations and vehicle state (at time k) given the recorded observations and control inputs up to and including time k together with the initial state of the vehicle
- Recursive approach: $P_{k-1} \rightarrow P_k$, Bayes theorem

Approaches to SLAM

- There are various approaches to solve SLAM problem
- Few popular approaches can be listed as:
  - ➢Kalman filter
  - ➢Particle filter
  - ➢Graph based
- Motion model describes relative motion of robot

References

- [1] H.F. Durrant-Whyte, "Uncertain geometry in robotics," *IEEE Trans. Robot. Automat.*, vol. 4, no. 1, pp. 23–31, 1988.
- [2] R. Smith and P. Cheesman, "On the representation of spatial uncertainty," *Int. J. Robot. Res.*, vol. 5, no. 4, pp. 56–68, 1987.
- [3] R. Smith, M. Self, and P. Cheeseman, "Estimating uncertain spatial relationships in robotics," in *Autonomous Robot Vehicles,* I.J. Cox and G.T. Wilfon, Eds. New York: Springer-Verlag, pp. 167–193, 1990.
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- [5] H. Durrant-Whyte, D. Rye, and E. Nebot, "Localisation of automatic guided vehicles," in *Robotics Research: The 7th International Symposium (ISRR'95)*, G. Giralt and G. Hirzinger, Eds. New York: Springer Verlag, pp. 613–625, 1996.
- [6] M. Csorba, "Simultaneous Localisation and Map Building," Ph.D. dissertation, Univ. Oxford, 1997.
- [7] M. Csorba and H.F. Durrant-Whyte, "A new approach to simultaneous localisation and map building," in *Proc. SPIE Aerosense,* Orlando, FL, 1996.