Introduction
Service robots will increasingly support daily work in business or home environments in the near future. Possible services are delivery tasks, cleaning services or home care. However, the distribution and thus further development of mobile robots is mainly dependent on the acceptance of society. An important criteria for this acceptance is the robot’s ability to interact with the environment. Therefore it is essential to give the robot a detailed model of its environment, i.e. the location of its interaction partners. In general, this knowledge can only be generated using sensory input. An explicit specification of a dynamic environment is usually impossible.

Multimodal Tracking Framework
Both camera tracking as well as laser tracking have their own specific advantages and drawbacks. To build a robust and accurate tracking system it is necessary to integrate independent tracking algorithms working on different sensor modalities. With an appropriate fusion algorithm the specific advantages of the sensors could complement one another to decrease the overall error. A typical multiple target tracking system consists of four blocks: sensor hardware, single sensor tracking, data fusion and association and track life management. A tracking system should be modular to allow addition, removal and other to decrease the overall error.

Sensor Fusion and Filtering
The problem of tracking can be considered as the detection of the state of a target. Therefore, the state vector of a tracked person at time \(t\) is modeled as a four-dimensional vector \((x, y, \dot{x}, \dot{y})\). This vector not only describes the position on the ground plane but also the velocity of the person. Since measurements of sensors contain errors it is impossible to derive the actual state of observed persons in a non-probabilistic way. Generally, a probability density function (pdf) is used to represent the state. Nonlinear Bayesian filtering can be applied to determine this pdf by taking every previous measurement into account, however practically it can only be applied when certain constraints hold. The Kalman filter and the particle filter are two frequently used methods to realize bayesian like filtering.

Real-Time Fusion of Multimodal Tracking Data
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Experimental Results
For experiments two SICK laser range finders mounted on a mobile service robot and a stationary camera at the laboratory of the TAMS institute are used. Due to the uncertainty of the camera tracking which is caused by noisy measurements and changing illumination conditions the outcome of the laser tracking is weighted higher. In figure 4 the observed target’s true trajectory is assumed as linear. Although the greater variance of the trajectory computed by the camera algorithm is obvious, the fused result has been improved compared to the laser tracking result.

Figure 4: Comparison of sensor modalities: Camera tracking (green) and laser tracking (blue) are fused by a particle filter (red).

Both sensor modalities are used to increase the accuracy and robustness of the tracking algorithm. Figure 5 shows a multimodal tracking of two persons. Figure 6 shows the results of a two-hour observation of the TAMS floor.

Figure 5: Increased robustness due to the use of multimodal sensors.

Figure 6: Results of a two-hours observation. The tracking starts when persons become visible to the sensors and ends when they leave the range of the sensors.

The camera-based tracking algorithm runs with a resolution of 640x480 pixel. With a standard pc our implementation achieves 25 fps while tracking 3-4 targets. The laser-based tracking achieves up to 30 fps due to the lower amount of data. Since the used particle filter is an efficient approximation of the bayesian filtering, our system should be able to ensure real-time constraints if an appropriate environment, e.g. RTLinux, is used.

Technical Aspects of Multimodal Systems
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Figure 3: A person is tracked in an image.

Figure 2: A person is tracked by a particle filter (left) and a Kalman filter (right). [Schulz et al. IJRR 2003]