Vehicle lane-level localization is a fundamental technology in autonomous driving. To achieve accurate and consistent performance, a common approach is to use the LIDAR technology. However, it is expensive and computational demanding, and thus not a practical solution in many situations. This paper proposes a stereovision system, which is of low cost, yet also able to achieve high accuracy and consistency. It integrates a new lane line detection algorithm with other lane marking detectors to effectively identify the correct lane line markings. It also fits multiple road models to improve accuracy. An effective stereo 3D reconstruction method is proposed to estimate vehicle localization. The estimation consistency is further guaranteed by a new particle filter framework, which takes vehicle dynamics into account. Experiment results based on image sequences taken under different visual conditions showed that the proposed system can identify the lane line markings with 98.6% accuracy. The maximum estimation error of the vehicle distance to lane lines is 16 cm in daytime and 26 cm at night, and the maximum estimation error of its moving direction with respect to the road tangent is 0.06 rad in daytime and 0.12 rad at night. Due to its high accuracy and consistency, the proposed system can be implemented in autonomous driving vehicles as a practical solution to vehicle lane-level localization.