Motion Control of an Assistive Mobile Robot Based on Model-based Predictive Control Scheme

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論 文 内 容 要 旨

The increasing shortage and cost of labor threatens the industries of many countries. Robots offer an effective solution to these problems. Automatic robots can ultimately replace human workers in production lines, but they have limited capabilities to carry out many tasks independently. To help human workers in task completion and increase their productivity, many researchers have developed human-assistive robots. Among the various types of robots, mobile robots are often employed in human–robot cooperation tasks because of their considerable working space and motion flexibility. In this research, we developed a human-assistive mobile robot (Fig. 1) that carries parts and tools for human workers in an automobile production line. For convenience, the mobile robot was designed to move in front of the human worker. The design was implemented on a four Alternated-wheeled mobile robot. There is no steering mechanism in the robot but it can move through 360°. Furthermore, the orientation and motion direction of this type of mobile robot can be independently controlled, enabling high motion flexibility.

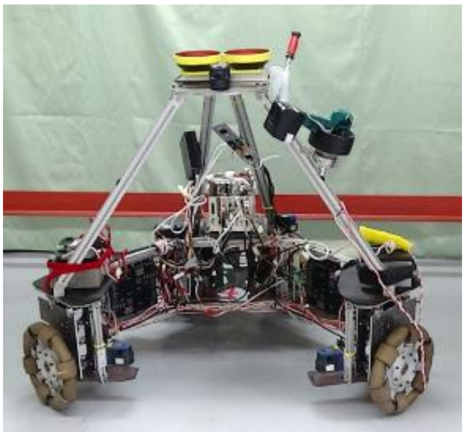

Fig. 1: Developed mobile robot

The safety and reliability of the omnidirectional mobile robot is deteriorated by hardware limitations; that is, the maximum speed and the nonlinear motion model of the robot are limited. Since our robot precedes the human worker, it cannot know the destination of the worker beforehand. If the motion of the target human exceeds the hardware constraints of the mobile robot, the human and robot may collide, or the human may vanish from the viewing field of the robot. Therefore, the objective of this study was to develop a motion control method for a human-assisting mobile robot that precisely predicts the human's motion. In this new motion control method, the assisting mobile robot keeps tracking and preceding a worker who walks at a speed exceeding its hardware limitations.

The human motion is predicted by a novel hybrid kinematic model that combines the inverted pendulum model with the commonly used constant velocity model. In developing this hybrid kinematic model, we referred to current researches on human walking. The two phases of the walking cycle are replicated by alternating between the two models. The inverted pendulum model calculates the motion of the upper body using the swing motion of the leg, whereas the constant velocity model assumes constant motion of the upper body during the sample time. The nonlinear motion of the inverted pendulum model is estimated by an unscented Kalman filter, whereas the constant velocity model (which is linear) is estimated by a standard Kalman filter. In our research, the current walking phase of the human worker was judged by comparing the swing speeds of the two legs. The effectiveness of the hybrid kinematic model was verified in experiments. The subject walked along a similar path at three different average speeds. The prediction results of the hybrid kinematic model were compared with those of the commonly used constant velocity model. At all three walking speeds, the proposed hybrid model achieved more precise motions than the constant velocity model, so it was chosen as the prediction model in our robot system.

The control framework is based on nonlinear model predictive control (Fig. 2). To achieve the contradictory tasks of preceding humans, avoiding collisions, and continuously tracking the target, a multi-objective cost function was developed (Fig. 3). The function constraints are the nonlinear kinematic model of the omnidirectional mobile robot and the hardware limitations. Infeasibility near the hardware limitations of the mobile robot's motion are avoided by a constraint softening method, which numerically calculates the optimal control input by using a sequential quadratic programming (SQP) algorithm. The calculation accuracy is improved by considering the computational time delay.

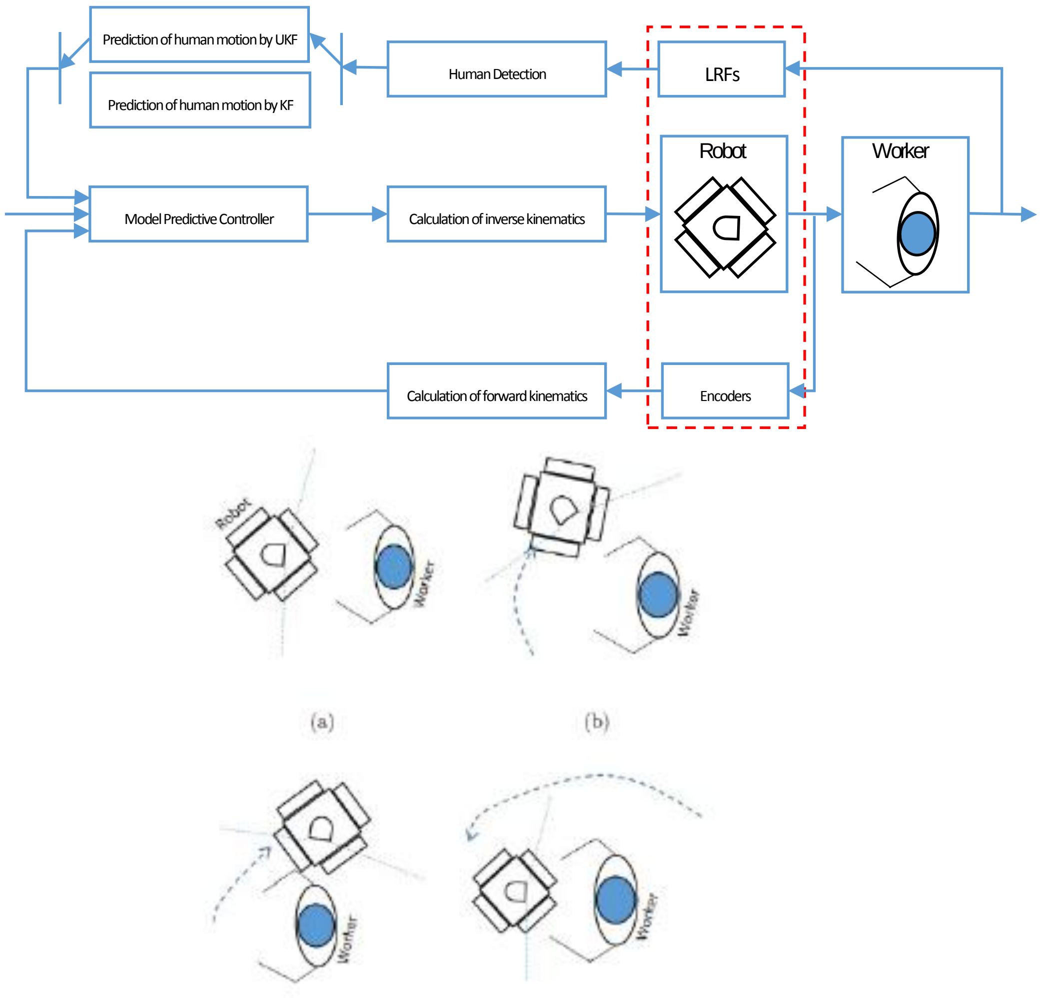

Fig. 3: Proposed strategy

The effectiveness of the proposed controlling strategy was demonstrated in experimental and simulation studies (Fig. 4). The simulation used the human motion data collected in the human motion experiment. In a comparative study of the simulation results, the model predictive control method outperformed the popular virtual spring method. The simulation study was followed by experiments on the real omnidirectional mobile robot. The subject walked along four paths with different shapes. On the final straight -line path, the subject momentarily walked at a speed exceeding the hardware limitation of the mobile robot. In this scenario, our proposed control strategy prevented human–robot collisions and vanishing of the human from the robot's viewing field. When the human's walking speed was within the robot's limitations, the mobile robot moved normally in front of the human.

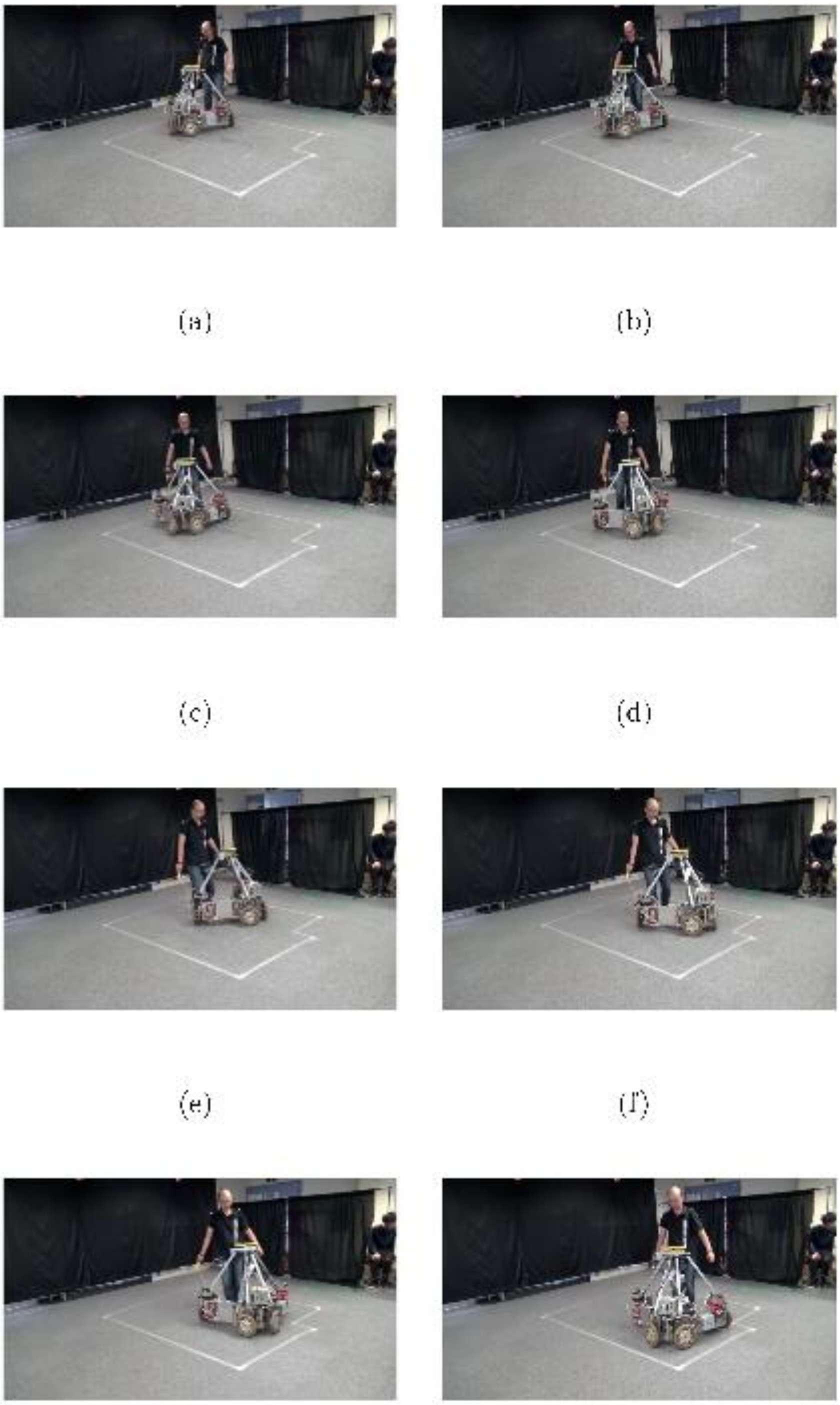

Fig. 4: S-path motion experiment