主論文の要約

論文題目：**Intelligent Cane Robot for Human Walking Assistance**（高齢者歩行補助用杖型ロボットの開発）

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Intelligent Cane Robot for Human Walking Assistance

The world is facing challenges of rapid aging population. The elderly people regarded as senior citizens draw attention because of their weakest and problematic living conditions. It is an important responsibility of democratic welfare state to solve the problems of aging and take care of elderly people. They suffer from low levels of physical strength due to muscle weakness, which affects their motion ability significantly. Restricted movement lowers the performance of most activities of daily living (ADLs). In addition, the growing elderly population causes the shortage of young people for nursing care. Therefore, walking-aid robots find their application in the nursing and therapy field for these mobility impaired people.

In daily life, the walking is one of the most important human activities. To improve the walking ability of the elderly, the walker-type rehabilitation robot has become a popular research topic over the last decade. There have been many intelligent walker-type robots comprising active or passive wheels and supporting frame. In the past several decades researchers have been addressing the needs of persons with mobility disabilities through alternative or augmentative devices. There are still many deficiencies in the present walker systems. First, many walkers are designed for the indoor environment. Second, most of them are big in size and/or heavy in weight. An indoor robot is often restricted within limited places. Big size makes it impossible to be used in narrow space and heavy weight restricts the maneuverability. Many elders and patients are not so weak that they have to be nursed carefully. Nevertheless, sufficient support, such as a cane or stick, is necessary to help them take a walk outside, which enables them to realize high-quality lives or accelerate the rehabilitation. In these cases, an intelligent cane system may be more useful than walkers due to its flexibility and handiness.

In part (A), a concept called “Intention Direction” was proposed to estimate the human walking intention. This quantized human intention is used to control the cane robot to move in the same velocity as human operator. An optimized motion control method is proposed for easing muscular fatigue during user walking in part (B). A novel device- “on-shoe load sensor” is proposed to test the effectiveness of fatigue relieving. As a nursing-care robot, the safety is the most important issue, in (C) and (D) we proposed the fall detection and prevention methods to guarantee the safety of both the human user and the cane robot.

A. Human Walking Intention Estimation: The recognition of user walking intention plays an important role in the study of the walker-type rehabilitation robots. From the point of view of the control system of robot, the walking intention provides a real-time reference trajectory for

the robot motion controller. Therefore, the more accurately the walking intention is inferred, the more satisfactory control performance of the robot may be obtained. To quantitatively describe the user's walking intention, a concept called "intentional direction (ITD)" is proposed. Both the state model and observation model of ITD are obtained by enumerating the possible walking modes and analyzing the relationship between the human-robot interaction force and the walking intention. From these two models, the users walking intention can be online inferred using Kalman filtering technique. Based on the estimated intention, a new admittance motion control scheme is proposed for the cane robot. Walking experiments aided by the cane robot on a flat ground and a slope are carried out to validate the proposed control approach.

B. Easing Muscular Fatigue: In some cases, the elderly cannot walk uniformly because one leg suffers from muscular weakness. When the affected leg is in the support phase, the cane robot should stop to absorb more strain than the affected leg. When the healthy leg is in the support phase, the cane robot should move forward according to ITD. In contrast to ITD, the motion of the cane robot should be controlled considering with the walking pattern characteristics of the elderly for guaranteeing safety and effectiveness. Therefore, an optimized motion control is proposed based on the characteristics gait pattern (CGP). An on-shoe load sensor was used to evaluate the reduction in muscular fatigue for the user's affected leg. This chapter discusses the "ability to support" which denotes a system's ability to reduce the load applied to the elderly and ease muscular fatigue. An on-shoe device is used to measure the reduction in load on the user's affected leg. In order to produce a high-efficiency and ergonomic cane for elderly.

C. As a nursing-care robot, the safety is a most important concern; before the elderly fall over, the cane robot should detect the sign of the falling and control the robot to assist the elderly to prevent it. Therefore a fall detection concept is proposed to estimate the risk of the falling based on the theory of zero moment point (ZMP) stability. An on-shoe sensor is used to measure the foot-ground reaction force and calculate the ZMP. The safety walking status is defined in the case of the ZMP is in the boundary of the support polygon. While the ZMP moving out of that boundary, the user will fall over. Obviously, an important feature indicating the user's falling state is the relative position between the ZMP and center of supporting triangle. This relative position can be described by a two-dimensional vector. While the user is walking normally, the ZMP should fluctuate around center of supporting triangle in a small area. This area differs from different people. When the user is falling down, the distance between ZMP and supporting triangle will increase suddenly. And the falling direction can also be easily obtained by observing vector.

D. In this chapter, a concept for enhancing the safety of human-cane robotic system is proposed to guarantee that both the human and cane robot can move without falling. For preventing the human subject from falling, the angle of human body and the acceleration of center of gravity (COG) should be less than some threshold. Although in a human-in-the-loop system, the human subject is regarded an uncontrollable object. However, while the user is falling over, the cane robot can move to an appropriately position and support the user for balance. As the

prerequisite condition that the cane robot support the human balance, the stability of cane robot should be ensured firstly. According Newton-Euler Law, a dynamic model is proposed to present the stability of human-cane robotic system. An impedance control is used to achieve position, posture and force control of iCane for fall prevention. The simulation and experimental results show the performance of fall prevention by using iCane.

In this thesis, an intelligent cane robot is proposed to aid the elderly and handicapped people walking. We focus on the "usability" and "safety" of cane robot for aiding the elderly to walk comfortably and safely. A concept idea named "ITD" is proposed to control the cane robot, and a fall detection and prevention method are used to guarantee the safety for both human subject and cane robot based on ZMP stability theory. For the future research, we would like to accomplish the "safety"; the hazard detection i.e. the potential risk in the environment should be investigated. The dangers including two sides, the inner and the external; the inner risk means the fall over risk of human subject and the tip-over risk of cane robot which we discussed above. By using the laser rangefinder which is fixed on the base of cane robot, the obstacles can be detected e.g. walls, steps or some moving object closing to the user.