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論文内容要旨

The current increase of longevity in Europe and other developed countries results in the fast growing population of the senior citizens. Older adults, people aged 65 or older represented 11% of the world population in 2009, and the percentage is expected to double by 2050. Fine motor skills, balance, and strength are among the abilities that decline with age. These age-related declines in physical abilities may negatively impact the elderly person's ability to maintain their independence in their home environment. Therefore, they need nursing support to perform their daily activities.

With the rise of the senior citizens' ratio in the populations, assistance robots can play an important role to reduce the workload of nurseries and increase the independence of elderly or people with disordered mobility to perform their daily activities with little help from people around them.

On the other hand, there are several public services that work to increase the accessibility of healthy users in the environment. Providing similar systems for physically impaired people can increase their mobility. But as of today, no such system exists. One of the main reasons for this absence is the fact that assistance devices are personalized and adapted and adjusted to each user's physical characteristics and ability. To propose a public assistance system for people with physical impairments, we need to be able to adjust and adapt them easily to each user. Since most of the users of this system are people with lack of strength and mobility, the process of the adjustment of the assistive devices needs to involve the users the least possible. For that, we firstly need to be able to detect and estimate the information needed for the most accurate possible adjustment and in an automatic way.

In this thesis, we contribute to resolving the problem of accessibility of public spaces for persons with reduced mobility. We specify an assistance system based on the cooperation of distributed robotic modules in the environment. The assistance is based on a set of collaborative assistance modules. This approach is called Ambient Assistance. It is part of the research project AccesSim, which focuses on the diagnosis of indoor and outdoor accessibility. It is characterized by adaptation to users' needs according to their physical abilities, their profile and their situation. This analysis must be done in real time, to detect the current situation and the intention of the person. It also relies on collaboration between the modules assistance and the environment.

In Chapter 2, we present a generic architecture of an ambient assistance multi-agent system to address the mobility needs of people with impairments in a public indoor space. Our proposed system is modular and expandable. This concept will be applied to public and private buildings like health centers, hospitals, theaters, train stations, etc. To make assistive devices usable by several users, we first need to adjust each of the assistive equipment to the proper and comfortable position of each of the human users.

In Chapter 3, we provide a method for estimating the parameters of disabled people before they use the assistive devices. We focus on the observation and estimation of the approximate human morphology remotely and without any physical contact between the users and the assistance modules. This measurement will be used to adjust the assistive devices appropriately for each user.

Among different human characteristics, height and weight are identified as the two important factors to provide adapted assistance and ensure comfort and security of the user. Body segment lengths can be calculated according to the height and can be used as the reference to adjust different parts of the assistance devices. Weight, on the other hand, is an indicator of the amount of force the assistive device needs to be able to support. It can also be combined with the height and human linkage data for creating the human model and the dynamic control of the equipment.

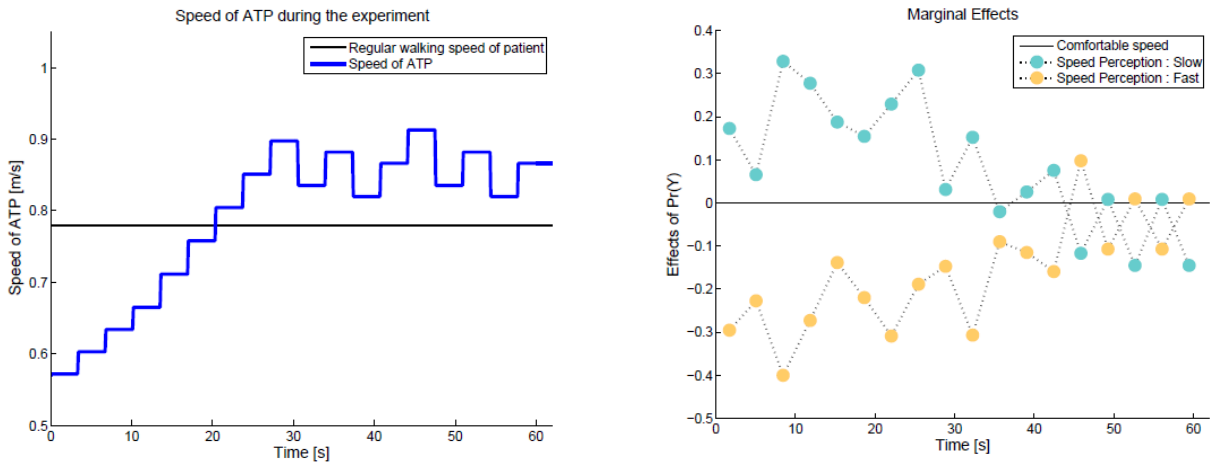
We use the Kinect for the measurements. Although there are several advantages in using Kinect, including its low price, its drawback is the low level of accuracy. Therefore, one of the objectives of this chapter is to increase the accuracy of remotely measured human data by Kinect. We improve the accuracy of the measurement by applying an adapted filtering process and a linear regression method. The result of the height measurement is accurate enough for the adjustment of different parts of the assistance equipments, including the height of the handles' of walkers and the height of seats in wheelchairs. The result of the work contributes in improving the accuracy of the human measurements done by Kinect.

In Chapter 4, we focus on adaptation and adjustment of speed of an ambulation assistance device with a

non-invasive generic and low cost sensory system. We propose an ambulation test platform (ATP) as an assistance device demonstrator of the ambient assistance system that was proposed in Chapter 2. Selection of the ambulation assistance is based on the fact that walking is reported as the most important form of physical activity to improve public health.

To derive the variable indicators for speed adjustment, we have conducted several experiments with physically impaired and healthy subjects. We apply Multinomial Logit Model (MNL) to the collected data to study the relevant indicators to identify the comfort speed of users. Based on the experiments results with the physically impaired patients, we observe that using our test platform can increase the average walking speed up to 30%.

In Chapter 5, we demonstrate the performance of our proposed method in real time. We are able to adjust the speed of an ambulation test platform to the comfortable speed of a hemiplegic patient. As shown in Figure 1, it took about 30 seconds to detect the patient's comfortable walking seed with ATP which was 10% faster than his natural walking speed. To ensure the safety and use the maximum physical capacity of users, we selected a set of indicators to estimate the perception of users regarding their walking speed in real time. These indicators could be used to adjust the speed of any type of intelligent, active, and passive walkers - to the comfort walking speed of the users.



(a) Speed of ATP during the experiment

(b) Estimation of speed perception

Figure 1. Speed adjustment of ATP – Experiment with a hemiplegic patient

Finally, chapter 6 concludes this dissertation.

All the contributions of this thesis are validated through experimental results with persons with reduced mobility.

論文審査結果の要旨

社会の高齢化とともに歩行する際に障害を持つ人が増加しており，障害を有していても，様々な支援機器を利用することにより，自立した生活を送ることが望まれている。歩行する際に障害を有している人は，一般に，杖や歩行器，車椅子などを使って移動を行うが，駅やショッピングセンター，病院といった公共の場所では，その環境に応じて設計された歩行支援ロボットを利用したほうが，安全な移動を行うために有効である。本論文では，公共の場所に設置され，誰でも使用できる共用化された歩行支援ロボットを，使用者の体格や障害の程度に適応して制御することを目的とし，利用者の体格情報や適切な移動速度を推定する手法を提案するもので，全編6章からなる。

第1章は序論であり，本研究の背景，目的および構成について述べている。

第2章では，利用者に応じて適切な歩行支援を提供するための，歩行支援ロボットの制御アーキテクチャを提案している。対象とする歩行支援ロボットは多くの人が共用するため，利用者の体格や障害の程度などに応じて，歩行支援ロボット自身が，支援部の位置や高さ，歩行速度の調整を行う必要がある。これは，公共の場所で複数の歩行支援ロボットを共用するための重要な知見である。

第3章では，深度センサを利用することで利用者の身長や体重，座位，立位の状態を推定する手法を提案し，深度センサの配置場所に応じて，体格の推定精度がどの程度変化するか，実験によって検証している。これは，歩行支援ロボットの操作ハンドルの高さを調整するために必要な情報であり，利用者の体格に応じて適切な支援を提供するための有用な成果である。

第4章では，歩行支援ロボットの制御に必要な，適切な歩行速度を推定する手法を提案している。利用者が歩行支援ロボットを用いて歩行を行う際に，歩行支援ロボットに加える力や，脚の運動を計測するためのセンサを搭載した歩行支援ロボットを開発し，それらのセンサ情報から得られる指標に対して，多重ロジスティック回帰分析を行い，利用者の適切な歩行速度を推定するための有意となる指標を導出している。これは，歩行支援ロボットを制御するための重要な成果である。

第5章では，歩行時に障害を持つ人による実験を行い，第4章で提案した手法の有効性を示している。被験者にとって歩行支援ロボットの移動速度が適切であるかをリアルタイムで推定し，その推定結果に基づいて歩行支援ロボットの速度を調整する実験を行っている。実験結果から，歩行速度はほぼ一定速度に収束するとともに，その速度が被験者にとって適切な歩行速度であることが示されている。これは，重要な成果である。

第6章は結論である。

以上要するに本論文は，公共の場所に設置された歩行支援ロボットを対象として，利用者の体格情報や適切な歩行支援速度を推定する手法を提案するもので，バイオロボティクスおよび機械工学の発展に寄与するところが少なくない。

よって，本論文は博士(工学)の学位論文として合格と認める。