User-Oriented Cognitive Interaction and Control for an Intelligent Robotic Walker

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Abstract. Mobility impairments are prevalent in the elderly population and constitute one of the main causes related to difficulties in performing Activities of Daily Living (ADLs) and consequent reduction of quality of life. This paper reports current research work related to the control of an intelligent robotic rollator aiming to provide user-adaptive and context-aware walking assistance. To achieve such targets, a large spectrum of multimodal sensory processing and interactive control modules need to be developed and seamlessly integrated, that can, on one side track and analyse human motions and actions, in order to detect pathological situations and estimate user needs, while predicting at the same time the user (short-term or long-range) intentions in order to adapt robot control actions and supportive behaviours accordingly. User-oriented human-robot interaction and control refers to the functionalities that couple the motions, the actions and, in more general terms, the behaviours of the assistive robotic device to the user in a *non-physical interaction* context.

1 INTRODUCTION

Elder care constitutes a major issue for modern societies, as the elderly population constantly increases. Mobility problems are common in seniors. As people age they have to cope with instability and lower walking speed [1]. It is well known that mobility impairments constitute a key factor impeding many activities of daily living important to independent living, having a strong impact in productive life, independence, physical exercise, and self-esteem [2]. Most people with mobility issues, patients or elders, have to use walkers in their everyday activities and they need the constant supervision of a carer. The social and economic significance of solving these issue should not be underestimated. Robotics seems to fit naturally to the role of assistance since it can incorporate features such as posture support and stability enhancement, walking assistance, navigation and cognitive assistance in indoor and outdoor environments, health monitoring etc.

This paper reports research work conducted in the frames of an EU funded research project MOBOT, aiming to develop an intelligent robotic rollator and to provide user-adaptive and context-aware walking assistance, Fig. 1(a). The main motivation behind

(a) (b) (c)

Fig. 1: (a) Left: Typical passive assistive device for elderly. Right: The robotic platform based on the rollator prototype equipped with a Hokuyo Laser Sensor aiming to record user's gait data. (b) Internal gait phases of human normal gait cycle. (c) Undecidability of the front-following problem in structured environments.

this work derives from our vision of developing and advancing robotic technologies enabling the development and deployment of cognitive assistive devices that can monitor and understand specific forms of human walking activities in their workspace, in order to deduce the particular needs of a user regarding mobility and ambulation. The ultimate goal is to provide context-aware support [3], and intuitive, user-adapted assistance to users experiencing mild to moderate mobility and/or cognitive impairments in domestic environments. To achieve such targets, a large spectrum of multimodal sensory processing and interactive control modules need to be developed and seamlessly integrated, that can, on one side track and analyse human motions and actions, in order to detect pathological situations and estimate user needs, while predicting at the same time the user (short-term or long-range) intentions in order to adapt robot control actions and supportive behaviours accordingly. User-oriented human-robot interaction and control refers to the functionalities that couple the motions, the actions and, in more general terms, the behaviours of the assistive robotic device to the user in a *non-physical interaction* context.

The experimental results are promising, demonstrating that our framework can be used efficiently and effectively to provide user-adapted mobility assistance that can enhance the functionality of such robotic devices. The ultimate objective of this work is to design a reliable pathological walking assessment system (that embodies several walking morphologies, allowing inclusion of new patients with different mobility pathologies) and incorporate this tracking and monitoring system in a context-aware robot control framework enabling a cognitive mobility assistance robotic device to provide user-adaptive walking support actions and intuitive assistive behaviours.

This paper is structured around three main components of the robot control architecture, namely: (i) human gait tracking and analysis, (ii) human action and gesture recognition for natural and intuitive interaction between the user and the robot assistive device, based on multimodal onboard sensorial data; and (iii) user-following control.

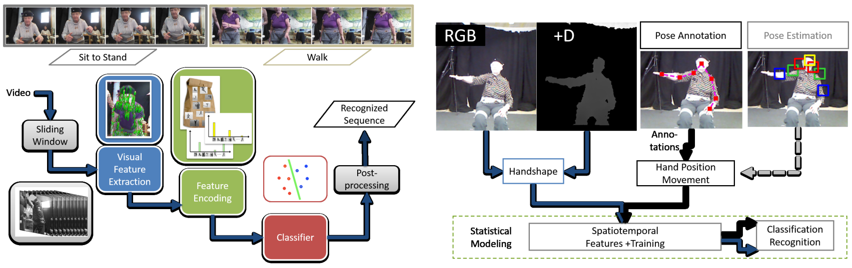
2 HMM-BASED GAIT ANALYSIS

The first part of this paper briefly describes research work aiming at developing a reliable pathological walking assessment system, that can operate on-line and in real-time enabling the robotic assistive device to continuously monitor and analyse the gait characteristics of the user in order to recognise walking patterns that can be classified as pathological requiring specific attention and handling by the system. The proposed system uses an onboard laser rangefinder sensor to detect and track user legs (a non-intrusive solution that does not interfere with human motion). With respect to gait analysis and assessment, as opposed to most of the literature available on the topic, the approach presented in this paper is completely non-intrusive based on the use of a typical non-wearable device. Instead of using complex models and motion tracking approaches that require expensive or bulky sensors and recording devices that interfere with human motion, the measured data used in this work is provided by a standard laser rangefinder sensor mounted on the prototype robotic rollator platform. A hidden Markov model (HMM) approach is used to perform statistical modeling of human gait. An HMM has well suited statistical properties, and it is able to capture the temporal state-transition nature of gait. In our work, we have proposed and analyzed extensively the properties of an HMM system and its applications for modelling normal human gait [4], as well as for pathological gait recognition [5]. The proposed model uses a seven-state representation that follows the typical definition of stance and swing phase events for normal human gait, which are depicted in Fig. 1(b). This paper presents the idea of this gait modeling framework in terms of segmenting the gait cycle and recognising different gait phases, which can be subsequently used to extract gait parameters, Fig. 1(b). These gait parameter consists of the *stride time* (the duration of the recognised gait cycle), the *swing time* (by using the stance and swing phase of the gait cycle), and the *stride length* (the summation of the absolute distances travelled by each leg during the gait cycle.

3 ACTION AND GESTURE RECOGNITION

An important part of the work that is briefly described in this paper concerns human action and gesture recognition enabling natural interaction between the user and the robotic assistant. A main thrust of our approach is based on the development of robust and effective computer vision techniques to achieve the visual processing goals based on multiple cues such as spatio-temporal RGB appearance data as well as depth data from Kinect sensors. Recognizing specific gestural commands and integrating those in the considered human-robot interaction context constitutes a major challenge.

Our approach to detect and classify human actions from continuous RGB-D video streams, captured by visual sensors on the MOBOT robotic platform, consists of the following main steps: visual feature extraction, feature pre-processing and encoding, and the classification. For the visual features we employ approaches such as spatio-temporal interest points by computing spatio-temporal energies via our multiscale Gabor 3D detector, [6], on the RGB or Depth visual streams, as well as dense trajectories. Overall, our system automatically detects human activity, classifies detected actions and localizes them in time, Fig. 2(a). All the above have been evaluated on both the MOBOT dataset as well as on known datasets found in the literature.



(a) (b)

Fig. 2: (a) Visual action recognition system. Top: Actions performed by patients in the MOBOT dataset. Bottom: Action localization and classification pipeline. (b) Visual gesture recognition. Multiple information channels are combined within a common framework.

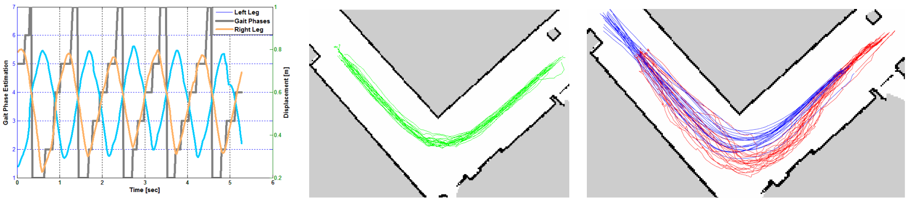
Gesture recognition concerns the communication of the elderly subjects with the platform via a predefined set of gestural commands. We have developed a visual front-end for gesture recognition that is based on the same approach used for action recognition, i.e. dense trajectories, feature encoding, and SVMs. This newer approach on gesture data showed that we can get roughly similar results to the ones obtained with our previous system, but without employing any manual (human provided) pose annotations. Our current gesture recognition systems has an average performance of about 70% on the MOBOT dataset, by using only motion-appearance features extracted from the RGB data, Fig. 2(b). Our ongoing plans include the incorporation of an automatic pose annotation system, [7], [8].

4 USER FRONT-FOLLOWING

The last important system component described in this paper refers to a control system that aims at supporting a “user-following” behaviour; that is, enabling the robotic rollator to follow and comply to the walking characteristics of the user, as well as deciding where the human actually wants to go without any physical interaction (i.e. without any force being applied on the handles of the Rollator) and remain in close vicinity to the user in case of need, Fig. 1(c). Results are promising demonstrating that such a framework can be used efficiently and effectively to provide user-adapted mobility assistance that can enhance the functionality of such robotic devices.

The current methodology implements a kinematic human-robot interaction control approach, essentially regulating a “virtual pushing” behavior. It is clear that the robot has no way of knowing where the human wants to turn by examining solely the human motion. This problem requires the addition of further information into the control loop by letting the human show the robot to turn left/right using some kind of feedback e.g. audio, posture, gestures etc. Thus, the human must also “steer” the robot and not just act as an observable for the robot. The control strategy for this problem is radically different from the *free space* following problem, and has received no attention in the literature.

Experiments with real users have shown that even though this control behavior is successful, it inserts a cognitive load on the users who try to steer the robot on the opti-



(a) (b) (c)

Fig. 3: (a) An exact gait phase recognition sequence for one subject, as estimated by the HMM-based approach. The grey line (axis on the left) depicts the gait phase transition. The blue and orange lines (axis on the right) show the displacement of the left and right leg, respectively, on the sagittal plane. (b) Traces of the baseline experiments (green). The subjects started on the right and progressed to the left. (c) Traces of the following experiments (Human-red, Robot-blue). The subjects started on the right and progressed to the left.

mal path they would have taken under normal conditions. As a result, the users deviate from their normal gait pattern in their effort to control the robot. Current research focuses on the development of a shared control user-assistance behaviour. Our approach considers user intent recognition by introducing the concept of dynamic undecidability, and employs a dynamic window method for local kinodynamic planning.

5 EXPERIMENTAL RESULTS

The experimental results presented in this section are based on data collected during a full-scale experimental study conducted at the premises of Agaplesion Bethanien Hospital - Geriatric Center (University of Heidelberg) at the frames of the EU-funded FP7 research project MOBOT. Patients with moderate to mild impairment, according to pre-specified clinical inclusion criteria, took part in this experiment. We have used a Hokuyo Rapid URG laser sensor (UBG-04LX-F01), mounted on the robotic platform of Fig. 1(a) (scanning was performed at a horizontal plane below knee level). A GAITRite system was also used to collect ground truth data, which will be used in future work for a formal clinical validation study. GAITRite provides measurements of the spatial and temporal gait parameters and is commonly used for medical diagnosis, [9]. An initial performance assessment of the HMM-based methodology regarding the extraction of gait parameters is presented. An example of the exact gait phase recognition sequence provided by the HMM-based approach for the full duration of the strides performed by one subject is depicted in Fig. 3(a), where the blue and orange lines show the displacement of the left and right leg in the sagittal plane, respectively, during five strides (axis on the right), while the grey line depicts the gait phase segmentation extracted by the HMM (axis on the left).

An initial evaluation with ground-truth data demonstrates that the HMM approach provides reliable and valid gait characterisation results, that could be eventually used for further classification of gait properties. Initial comparison with other approaches (e.g. a rule-based methodology based on raw data spatiotemporal filtering) also demonstrates that the added complexity of the HMM approach, w.r.t more basic tracking methodologies, is necessary for improved accuracy. These results are very promising clearly depicting the capacities of the proposed HMM-based methodology to successfully segment the gait cycle and recognize the specific gait phases, extracting comprehensive information about the specific action of each leg, which can be very useful for medical diagnosis. Nevertheless, the results demonstrate that there is significant space for increasing the accuracy of the system. Further comparative analysis and full-scale validation of this methodological framework constitutes one of the main objectives of current research work.

The user front-following control scheme, has been implemented on a Pioneer 3DX differential drive robot, with a Hokuyo UBG-04LX-F01 laser range finder. The experiments considered here, aim to assess the gait pattern of the users with and without the robot following them from the front. Ten healthy subjects were asked to walk naturally from an initial predefined position, around a corner and stop at a designated target position. The subjects were tracked with the laser scanner mounted on the robot, which in turn was placed statically at the head of the corner, overseeing the experimental field. In post processing, using the detection algorithm, the centroid traces were extracted, providing the Baseline data, Fig.3(b). Following, the subjects were asked to perform the experiment again, but with the robot following them from the front, Fig.3(c).

We see that the Robot path distribution is more similar to the Baseline distribution than the User' distribution. This means that the users actually tend to "drive" the robot to the path they consider "optimal" i.e. the one that *they* would take under normal conditions (the baseline paths). Doing so, they deviate from their normal gait patterns. Also, we see that the users cover much more area trying to steer the robot, than when walking normally, which is almost twice the area the robot covers. This can be regarded as a measure of cognitive load since it shows that the users walk through a wider area.

6 CONCLUSION AND FUTURE WORK

This paper presents current research work that aims at the development of an intelligent robotic rollator to provide user-adaptive and context-aware walking assistance. To achieve such targets, a large spectrum of multimodal sensory processing and interactive control modules need to be developed and seamlessly integrated. This paper focuses on user-oriented human-robot interaction and control, by which we refer to the functionalities that couple the motions, the actions and, in more general terms, the behaviours of the assistive robotic device to the user in a *non-physical interaction* context. The paper summarizes recent research advances and scientific challenges aiming towards three complementary directions: 1) the development of a reliable gait tracking and classification system, for which we propose an approach based on HMMs, which can operate online by processing raw sensorial data provided by an onboard laser rangefinder sensor, 2) the development of the multimodal processing system for human robot interaction (HRI): action recognition, and gesture recognition, and 3) the development of a control system that can support a "user-following" behaviour, that is, enable the robotic rollator to follow and comply to the walking characteristics of the user without any physical interaction (i.e. without any force being applied on the handles of the Rollator) and remain in close vicinity to the user in case of need.

This paper summarizes the framework and presents experimental results obtained using real data both from patients and normal subjects. These results are very promising depicting the capacities of the presented methodologies, both in terms of action recognition and gait characterisation as well as regarding robot motion control based on non-contact sensorial data. Nevertheless, the results demonstrate that there is significant space for increasing the accuracy of the system. Further comparative analysis and full-scale validation of this methodological framework constitutes one of the main objectives of current research work.

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