ICT-Supported Bath Robots: Design Concepts

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Abstract. This paper presents the concept and the architecture of the I-SUPPORT service robotics system. The goal of the I-SUPPORT system is to support and enhance older adults mobility, manipulation and force exertion abilities and assist them in successfully, safely and independently completing the entire sequence of showering tasks, such as properly washing their back, their upper parts, their lower limbs, their buttocks and groin, and to effectively use the towel for drying purposes. Adaptation and integration of state-of-the-art, cost-effective, soft-robotic arms will provide the hardware constituents, which, together with advanced human-robot force/compliance control will form the basis for a safe physical human-robot interaction that complies with the most up-to-date safety standards. Human behavioural, sociological, safety, ethical and acceptability aspects, as well as financial factors related to the proposed service robotics system will be thoroughly investigated and evaluated so that the I-SUPPORT end result is a close-to-market prototype, applicable to realistic living settings.

1 Introduction

One important measure of morbidity and quality of life is a persons ability to perform Activities of Daily Living (ADLs) such as washing the body, dressing, transferring, toileting and feeding [1], [2]. Difficulties in performing ADLs are a significant predictor of nursing care home use, significant family financial burden, use of hospital services, use of physician services, and mortality.

Washing the body (either showering or bathing) is one of the most complex and least basic activities and, thus, is among the first loss of function across ADLs.Furthermore, older adults showering is reported as one of the first ADLs that residents of a nursing home population lost the ability to perform, [1]. This clearly suggests that support in shower and bathing activities, as an early marker of ADL disability, will foster independent living for persons prone to loss of autonomy and relieve the caring and nursing burden of the family, domiciliary services, medical centers and other assisted living environments.

This paper presents the concept of the I-SUPPORT service robotics system, which will be developed in the context of the EU Horizon2020 Project I-SUPPORT. The proposed service robotics system envisions the development and integration of an innovative, modular, ICT-Supported service robotics system that supports and enhances frail older adults' motion and force abilities and assists them in successfully, safely and independently completing the entire sequence of showering tasks, such as properly washing their back their, upper parts, their lower limbs their buttocks and groin, and to effectively use the towel for drying purposes. The I-SUPPORT concept once developed can be readily transferred to the bath environment too.

2 Target Group and System Requirements

The bathing process involves many functional challenges for the aged population, [3]-[5]. The primary target group includes senior citizens starting to get increasingly frail, who are able to live independently but experience mild or medium functional disabilities (notably, decline in physical strength and flexibility) and increasing difficulty in their ability to perform ADL, notably showering and bathing activities, [3]. In fact this population has been defined by [6], as the presence at least of one on the physical frail indicators among mobility, muscle strength, nutritional intake, weight change, balance, endurance, fatigue, and physical activity. Furthermore, the proposed I-SUPPORT system would benefit all individuals, regardless of their age, suffering from functional impairments, including persons with neurological diseases resulting in muscle weakness or balance problems, as the result of an acute clinical event (e.g. stroke), or a consequence of neurodegenerative progressive disorders (e.g. Parkinson Disease, multiple sclerosis), which can cause deficits of strength in one arm or leg or deficits of balance that results in varying degrees of difficulty in performing bathing activities. Secondary users are formal and informal carers of primary users, including medical staff of all kinds, nurses, next-of-kin, etc.

The major requirements of I-SUPPORT system include safety, reliability, acceptability by users, adaptability to users actions, intentions, cognitive and mobility needs and capabilities. Furthermore, given the sensitive nature of the shower activity, such a system must take into account ethical, sociological and gender considerations. As the ultimate goal is to reach application in real life settings, it should be modular, flexible and cost-effective, requiring minimum interventions to the user bathroom environment.

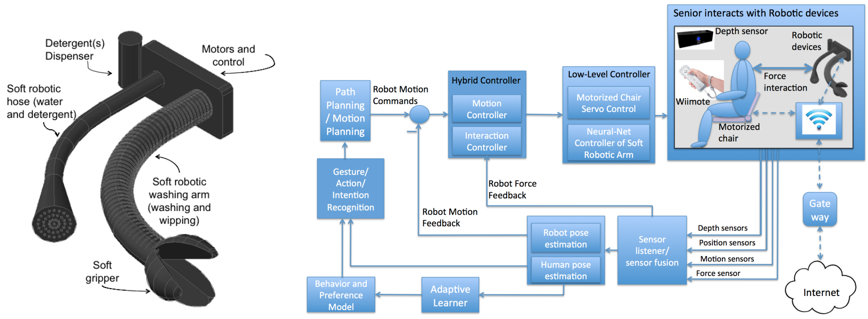
3 I-SUPPORT System Description

Under the scope of the aimed functionality the showering tasks are classified into: (i) transfer activities: sit-to-stand and stand-to-sit in the bathing space, and (ii) washing activities: pouring water, soaping, scrubbing body parts, rinsing and drying. The service robotics system should accomplish these showering tasks in a semiautonomous mode where the goal of the automation is to fill a gap left by the sensory/motor weakness or impairment of the frail senior citizen and the degree of autonomy will depend on the user abilities and preferences. The system components and the system architecture for realising the semiautonomous I-SUPPORT service robotics system are presented in a concept level in the following paragraphs, Fig. 1(b).

3.1 Robotic devices

I-SUPPORT system will accomplish these tasks by integrating three devices which will meet the motion and force requirements of the showering tasks: (a) **a motorized shower chair:** a motorized chair dedicated to the provision of the stand-to-sit and sit-to-stand functionality, (b) **a robotic shower hose:** a soft robotic arm dedicated to the provision of pouring water, soaping etc., (c) **a robotic washer/wiper:** a soft robotic arm dedicated to the provision of scrubbing wiping, drying etc. functionality.

The proposed service robotics devices entail high degree of human-robot interaction since they involve frequent physical interaction. Due to this close coupling of the system with the user, safety is of major concern and is among the highest priority requirements of the service robotics design. The I-SUPPORT consortium opts for a soft robotic arm as part of the proposed service robotics system as shown in Fig. 1(a).



(a) (b)

Fig. 1: (a) Concept of the two robotic devices: (i) robotic hose and (i) robotic washing arm. The length of the robotic arm can vary depending the shower space and the ergonomic design. The concept is modular, self contained and easily interfaced with a conventional tab shower infrastructure. (b) Block diagram of the I-SUPPORT service robotics system architecture.

Their distributed compliance (i.e. the entire structure of the robotic arm is soft) in combination with the soft material (silicon, rubber, etc.) generates little resistance to compressive forces and produces small impacts during contact with humans, [7], [8]. Moreover, if the soft-robotic arm has adjustable stiffness, then arm sections that interact with the user will exhibit low stiffness while sections responsible for supporting the payload (i.e. lifting a sponge, a folded towel, or simply the rest of the soft-robotic arm structure) will exhibit high stiffness. To this end, the robotic arms are continuum robots of tubular shape, with intrinsic compliant characteristics (i.e. built with soft materials and are deformable and intrinsically safe).

3.2 Human robot interfaces

The interface of the human with this devices will be accomplished in two ways:

A direct natural haptic interaction: Human-robot interaction can be provided in a robot passive control operation mode by natural haptic interaction. The soft robot(s) are guided to the appropriate position by the user, through direct physical (haptic) interaction. In this case, the controller is in charge of actively adapting the apparent mechanical properties of the robot arm, to ameliorate the haptic feeling this interaction creates to the elderly population. The robot performs gravity and friction compensation and this way holding and moving the soft-robot arm becomes transparent to the user.

Remote control / Sensor bar: Human-robot interaction can be provided by telemanipulation of the soft robots. The user using a remote controller, i.e. a lightweight remote controller similar to those used in video games (e.g. Wiimote), will guide the soft-robotic arms. It is envisaged that the senior citizen seated on the shower chair, would be able to grasp the remote controller and perform small smooth motion patterns, as she/he would do for washing her/himself. These motion patterns would not need to be accurate and detailed as they will be intelligently translated into actuator commands and robotic motions in a master/slave mode (user/robot). Thus, simple, not accurate, weak (no need to apply force) and most importantly natural motions of the user's hand would provide the data required and interpreted to robots actions that would perform tasks like rinsing, soaping and scrubbing.

3.3 Robotic cognition system

The goal is the development of integrated service robotics system that are responsive to the user's needs and are fully adaptable to the users behaviour and abilities, in particular to his/her manipulation and force exertion abilities. For this purpose the I-SUPPORT service robotics system will integrate robot cognition which will be based upon:

Action and gesture recognition: To be able to give the appropriate aid to frail senior citizens, it is necessary for the I-SUPPORT system to successfully interpret the users intent and adapt to his/her capabilities on-line and real-time. Therefore, pivotal role in the I-SUPPPORT concept plays the design and development of cognitive robotic and learning algorithms for real time gesture and intention recognition, which based on a set of control primitives, are responsible for choosing the most likely motion intention, given a set of measurements, and assist its completion. Based on these identified motion intentions, the control system of the I-SUPPORT will generate customisable motion and force commands for the robotic components that will assist the senior citizen to accomplish the showering tasks.

Customization of automation to the senior user profile, needs and preferences: Contextual system and machine learning are natural candidates to accomplish customization. We hypothesize that an optimal trade-off in human robot control will be unique to: (i) the users sensory motor capabilities, (ii) their personal preferences, (iii) their medical condition and (iv) possibly also the task at hand. For this purpose we will develop personalized washing and drying behaviors, which take into account users preference and previous sensorimotor experience. Starting from a reference model of the human body, which defines the kinematics and dynamics of the human body based on global body parameters such as height, weight, we will derive individual models of the different users. In addition, we will develop methods based on reinforcement learning techniques, which take into account user rituals, behaviours related to bathing and preferences.

3.4 Control architecture

A multilayered architecture is proposed to cope with the multiple levels of the control problem (shape, stiffness, position, and force/impedance control). The control problem cannot be completely decomposed into independent distinct layers of control. Moreover, there is a ”meta redundancy” in the problem, in the sense that the same control objective can be accomplished with different combinations of actions in the various control levels. Therefore, the multi-layer architecture has to seamlessly integrate all levels of control, addressing problems that range from achieving low-level control specifications in terms of motion planning and tracking performance, to embedding high-level control behaviours involving task and path planning.

All modalities of the multilayered control architecture involve human-robot interaction (HRI) control, where both the soft robotic arms interacts (physically or non-physically) with the part of the body. A possible approach to this problem of complex interaction between the soft-arm and its environment is not to use analytic modelling techniques but, instead, to encode the relevant control skills in internal models built by learning from experience in the real physical world. The control problem can be formulated as a hybrid position/force control strategy, based on an adaptive dynamic impedance control structure, where 3D human-robot interaction tasks will be performed combining force feedback and visual servoing in an uncalibrated workspace. Successful implementation of the algorithms will validate the hypothesis that the active compliance capabilities allow the successful implementation of complex human-robot interaction schemes.

3.5 Context awareness system

The I-SUPPORT service will also integrate context awareness and alerting functionalities and will, thus, raise proper alerts in case of events (e.g. the water temperature is too high, the bathroom is overly humid, the bathroom window is open, etc.). As falls are frequent in the bathroom/shower environment, I-SUPPORT will also integrate fall detection so that next of kin or a health centre is immediately notified via e-mail or telephone call. A wearable sensor, such as a wristwatch with integrated IMU units, will be employed which in combination with the integrated depth sensors will detect falls and trigger alerts. To cater for the needs of users in the beginning of moderate cognitive disability, the I-SUPPORT system will also detect long inactivity of the user, which may indicate that the user is disoriented and will trigger proper reactions (e.g. provide clear and simple instructions how to proceed, or alert next of kin/carers).

3.6 User and robot pose estimation

User acceptability is of major concern, therefore we will take into full account all relevant ethical and sociological considerations; we will put special emphasis on the type of information that is collected during the shower activities and how this information is processed for 3D reconstruction and robot control purposes. We will develop efficient computer vision algorithms for accurate human pose estimation and limb localisation from Depth measurements and not from RGB camera measurements. Depth measurements capture the shape and geometry of the user but do not capture detailed face and body features that might reveal the user's ID.

This is a challenging problem where information gathered from more than one depth sensor captured in a noisy environment should be fused and yield accurate robot and human pose estimation. For this purpose, during an off-line training stage we will be using statistical machine learning to train Deformable Part Models for 3D human pose estimation; at test time we will use combinatorial optimization, such as Branch-and-Bound to rapidly deliver exact estimates of human pose. Similar algorithms will be developed to perform 3D localization of the robotic manipulator, treating it as a multi-part 3D shape. On the hardware side this will involve installation of the depth sensors and development of encasing for ensuring depth sensors are waterproof.

4 Conclusion

The I-SUPPORT service robotics system will support and enhance older adults mobility, manipulation and force exertion abilities and assist them in successfully, safely and independently completing the entire sequence of showering tasks, such as properly washing their back, their upper parts, their lower limbs, their buttocks and groin, and to effectively use the towel for drying purposes. Adaptation and integration of state-of-the-art, cost-effective, soft-robotic arms will provide the hardware constituents, which, together with advanced human-robot force/compliance control that will be developed within the proposed project, will form the basis for a safe physical human-robot interaction that complies with the most up-to-date safety standards. Human behavioural, sociological, safety, ethical and acceptability aspects, as well as financial factors related to the proposed service robotics system will be thoroughly investigated and evaluated so that the I-SUPPORT end result is a close-to-market prototype, applicable to realistic living settings.

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