Wearable Haptics for Human Guidance in Structured and Unstructured Environments

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Abstract—In real world scenarios, visual and auditory channels may be overloaded with a huge quantity of stimuli resulting in some cases inefficacious or unusable. A possible solution is to provide information exploiting an underutilized sense, i.e., the sense of touch. As the sound, a tactile stimulus consist in a signal with varying frequency and amplitude. Differently from the auditory feedback, tactile sensation directly engages our motor learning system with extraordinary sensitivity and speed. Moreover, tactile communication can be used in situations where visual or auditory stimuli are distracting, impractical or unsafe. In this abstract, we report our main results showing the capability of wearable haptics interfaces to guide human in structured and unstructured environments.

I. INTRODUCTION

Let us assume that single or multiple humans want to reach a final location in a large environment. Demonstrative scenarios are for instance, assisting older adults or visually-impaired persons, and helping people in a dangerous situation with poor visibility and no way of hearing clearly due to environmental noise. In these contexts, haptic guidance has been successfully exploited in the last years. Closely related are the researches presented in [1], and [2]. In [1], a vibrotactile belt is used to guide humans towards goal points. Scheggi et al. in [2] presented a new paradigm to assist navigation of mixed human–robot teams using haptic information. While kinesthetic feedback is common in haptic systems, we exploited wearable vibrotactile interfaces, since tactile devices are generally more portable, less encumbering, and have a wider range of action than the kinesthetic ones [3]. Compared with existing strategies, our idea has the following pros: (i) the user has the hands free, thus other physical tasks may be accomplishable; (ii) it is easy to extend the physical interaction to multiple users; (iii) since we are using wearable devices, the proposed approach can be combined with other body parts; (iv) the user is not constrained: directions and walking speed are only suggested.

II. DESCRIPTION OF THE HAPTIC INTERFACE

Tactile vibratory sensitivity is influenced by the spatial location on the body, the distance between the stimulators, the frequency of stimulation, and the age of the user. Studies have demonstrated that vibration is better sensed on hairy skin due to its thickness and nerve depth, and that vibrotactile stimuli are best perceived in bony areas [4]. In particular, wrists and spine are generally preferred for detecting vibrations, with arms and ankles next in line [5]. Due to the aforementioned considerations and since our aim is to design an intuitive and non-obtrusive device which could be easily worn, we concentrated our effort on the development of vibrotactile elastic band, that can be worn on the ankles as well as on the wrists. Starting from the results presented by Scheggi in [6] and Lisini Baldi in [7], we decided to use the bilateral configuration, that required two devices, one for each body part. Please refer to [6] for further details about study procedures and results. Technical aspects of the wearable devices and positioning evaluation are reported in [7]. Our contribution consists in the development of approaches for suggesting directions and gait cadence by means of haptic interfaces. Complementary scenarios are considered: i) the environment is unknown and not structured with sensors/cameras; ii) the map of the environment is available and the user can be localized into.

III. HUMAN GUIDANCE IN UNSTRUCTURED ENVIRONMENTS

For what concerns the guidance in an unstructured environment, we studied and developed two guidance policies. The goal of the former is suggesting direction to blind people, the latter aims at creating a system for “feeling” a partner remotely while walking [8]. Both strategies exploit the internet connection as mean to exchange vibrotactile cues. In the proposed scenarios the map of the environment is not necessary. In the first case a mobile phone streams a video of the surrounding to a remote operator, whereas in the second the users have no visual impairments and localization is not required.

A. Suggesting directions

As a first step, we present a remote guidance system for visual impaired people. In fact, blinds encounter many difficulties in living an autonomous life, due to the reduced capability to perceive the surrounding environment. In particular, navigation and orientation seem to be very challenging when moving in unknown domains. Trained guide dogs and canes are useful for collision avoidance and obstacle warning but they do not provide directional information to guide visually impaired toward a desired location. Based on these observation, we proposed an effective assistive system for visually impaired. The blind is equipped with a mobile phone for video streaming, two vibrotactile bracelets and a cane which is used to avoid potential obstacles. Note that the proposed vibrotactile devices do not substitute the cane or the guiding dog for obstacle avoidance; they represent assistive devices which provide directional information in order to properly reach the desired location. A remote volunteer is in charge of controlling the video stream.
and suggest directions according to the final destination and the awareness of surrounding risks. The haptic cues are transmitted via TCP datagrams and 3G/4G network to the user smartphone, which communicates with the vibrotactile bracelets using the Bluetooth protocol.

B. Suggesting walking pace

Once the capability of steering humans via haptic stimuli was assessed, we explored the possibility of suggesting walking pace. Walking is an essential activity for a healthy life, which is less tiring and more enjoyable if performed together. The difficulties we have in performing sufficient physical exercise, principally lack of motivation, can be overcome exploiting the social aspect. However, our lifestyle sometimes makes it very difficult to find time together with others who live far away from us to go for a walk. In this respect, we developed a novel system enabling people to have a “remote social walk” by streaming the gait cadence between two persons walking in different places, to increase the sense of mutual presence.

The system exploits the vibrotactile devices worn at the ankles which provide timing cues for the cadence synchronization. The gait cadence is measured using a pressure sensor immersed into a silicon insole and connected with one of the haptic interfaces. The system detects the steps and then sends its feedback to the user's smartphone that communicates with a dedicated server. Finally, each social walker smartphone receives the gait cadence updates from the server and adjusts the vibrations accordingly. A first experimental session confirmed that humans can follow a time varying artificial rhythm perceived via ankle vibrations. We then assessed that the tracking performances are retained when the virtual reference is replaced with a human gait cadence with a dedicated set of experiments. Finally, basing on the facts confirmed by previous experiments, we obtained experimental evidence that two humans, walking simultaneously but not in each other’s proximity, perceiving the companion rhythm, synchronize their gait cadence using our system.

IV. HUMAN GUIDANCE IN STRUCTURED ENVIRONMENTS

Studies of novel methods and policies involved also the capability of guiding people in structured environments. In this context, we initially developed an algorithm for suggesting directions [9], then we proposed a system for regulating the walking cadence [10].

A. Suggesting directions

In this study, we employ an effective haptic policy to easily display directional stimuli. In this regard, we consider that the human locomotion can be approximated by the motion of a unicycle system, i.e., nonholonomic constraints similar to those of mobile robots seem to be at work when a human is walking [11]. Without lack of generality, we assumed that the human is free to select her/his desired walking speed. Control signals (i.e., haptic stimuli) are sent to the users in order to steer their locomotion. The proposed method is evaluated in three different scenarios consisting of: (i) Two users; (ii) two users and a static obstacle; and (iii) three users. In all scenarios, the users have to move toward their respective goal areas, while avoiding reciprocal collisions and collisions with the environment. In order to provide easily-recognizable cues, the device could elicit only three basic behaviors (“turn left, turn right,” and “go straight”). The algorithm developed to safely navigate the users in dynamic environments is an the extension of the Optimal Reciprocal Collision Avoidance (ORCA), adapted for non-holonomic robots (NH-ORCA) [12]. The algorithm provides a sufficient condition for each agent to be collision-free for at least a fixed amount of time into the future. Each agent takes into account the observed velocity and pose of the other agents in order to avoid collisions with them. Then, the optimal velocity is selected by using linear programming. Then, a set of holonomic allowed velocities is computed. Following that, the algorithm calculates the optimal holonomic velocity, which is mapped to the corresponding non-holonomic control inputs for the agent. Positions are estimated using a camera-based tracking system, combined with an Extended Kalman Filter which provides an estimate of the variance, and hence the standard deviation, of the measured quantities. These values are taken into account by the obstacle avoidance algorithm.

B. Suggesting walking pace

As a conclusive step, we present a system to guide humans in structured environments, with the aim of reaching simultaneously a rendezvous point. Exploitation of the proposed approach are assistive and rescue scenarios, human-human collaboration, as well as rehabilitation. Cadence is suggested to the users via two vibro-tactile elastic bands placed on the ankles. To reach the same point at the same time, users have to adapt their walking pace to the one displayed by the haptic interfaces. The user position, is computed in predefined locations called checkpoints. Here the walking parameters, thus the rhythm, are updated. The user retains complete access to audio and visual information from the environment, so that he/she is ready to react to unexpected events (e.g., moving obstacles). We tested the system with the following setup: User1 is closer to the goal point than User2. To reach the rendezvous point at the same time, User1 has to keep a slow pace, while User2 has to increase the walking cadence. Every 30 meters a checkpoint was positioned. All the participants were able to reach the rendezvous point with a low average error both in time and space.

REFERENCES