Human Rendezvous via Haptic Suggestion*

Gianluca Paolocci[1,2], Tommaso Lisini Baldi[1], and Domenico Prattichizzo[1,2]

[1] University of Siena, Department of Information Engineering and Mathematics, Via Roma 56, 53100 Siena, Italy.

[2] Istituto Italiano di Tecnologia, Department of Advanced Robotics, Via Morego 30, 16163 Genova, Italy.

Abstract. In this work we propose a wearable system to guide humans in structured or unstructured environments, with the aim of reaching simultaneously a rendezvous point. Directional and rhythmic cues are provided using wearable haptic interfaces placed at the subject's ankles. The walking pace guidance is achieved through the synchronization of the user's step cadence with the rhythm suggested by tactile cues. Directional hints are provided using different vibro-tactile patterns when reaching predefined locations called *checkpoints*. Here the estimated walking parameters are updated. The user retains complete access to audio and visual information from the environment, thus he/she is ready to react to unexpected events (*e.g.*, moving obstacles). Exploitation of the proposed approach are assistive and rescue scenarios, human-human collaboration, as well as rehabilitation.

Keywords: Human guidance · Haptic communication · Cadence suggestion.

1 Introduction

Human body guidance is exploited in several contexts, ranging from rescue procedures to training and rehabilitation [5,1,3]. Novel and promising technologies allow to track and guide individual limbs, as well as complex movements requiring high coordination [8,9].

In this work, we focus on a fundamental human activity: locomotion. In particular, we want to address the problem of guiding humans in structured and unstructured environments. The aim is suggesting walking pace to multiple users to reach the goal destination at the same time.

Over the years, haptic stimuli have been found an effective, yet non-intrusive way for suggesting directions and pace cues to users [7,4]. They represent an interesting way to provide information when audio and visual modalities are not available or overloaded (*e.g.*, vision is temporarily impaired).

* The research leading to these results has received funding from the European Union Horizon 2020 research and innovation programme - Societal Challenge 1 (DG CONNECT/H) under grant agreement n. 643644 of the project "ACANTO: A CyberphysicAl social NeTwOrk using robot friends".

A representative scenario of the demo is depicted in Fig. 1, where two participants (*User1* and *User2*) are guided, by means of haptic interfaces, to reach at the same time a shared goal location.

Our method exploits the sensory-motor entrainment to suggest a specific walking cadence [2,10]. It is known that the frequency of a cyclic movement, such as walking and running, can be affected by rhythmic sensory inputs and can smoothly converge to the input rhythm. For example, when people walk while listening to music, their step cycle gradually conforms to the rhythm of the music.

We showed in our previous work [6] that subjects adapt to the rhythm provided by the haptic interfaces with very low effort and without overloading other sensory input channels (visual and auditory). Two different body locations were tested to assess which was the most suitable to convey the walking pace. Experimental results and questionnaires showed subjects to prefer the rhythmic cues displayed at the ankles instead of the wrist positioning. Vibrations provided at the forearms were considered as disturbances for manipulation tasks, and the proximity of the haptic stimulus with the foot during the heel strike let subjects synchronize more easily with the external rhythm.

2 Material and methods

Our solution relies on flexible vibro-tactile interfaces placed at the ankles, providing cadence and direction suggestions to the users. In Fig. 2 the haptic devices are described. In the experiments, subjects were asked to adapt their walking cadence to the rhythm proposed by the wearable interfaces.

2.1 System overview

The desired cadence is suggested to the users through rhythmic vibrations provided by remotely controlled elastic haptic bands. Each wearable haptic interface is composed by two water-proof vibro-motors. Whenever a trigger is sent to a haptic device, the motors vibrate for 0.1s at a frequency of 250Hz, delivering a haptic stimulus to the wearer. The vibration frequency has been selected with respect to the user's maximal sensitivity, achieved around 200-300Hz [11] (the human perceptibility range is between 20Hz and 400Hz). A pressure sensor is placed under the right heel to detect contact with ground and count the number of steps. The step count is necessary for post-experimental analysis, and is a valid tool to update walking parameters (*i.e.*, the estimated step-length) in unstructured environments. An ad-hoc algorithm is used to control the haptic interfaces through external devices (laptop, smartphone). Information about the path and the time to complete the rendezvous are entered to calibrate the system. The communication is realized with an RN-42 Bluetooth antenna connected to a 3.3V ATmega328 microcontroller, which is also in charge of the motors activation and timing.

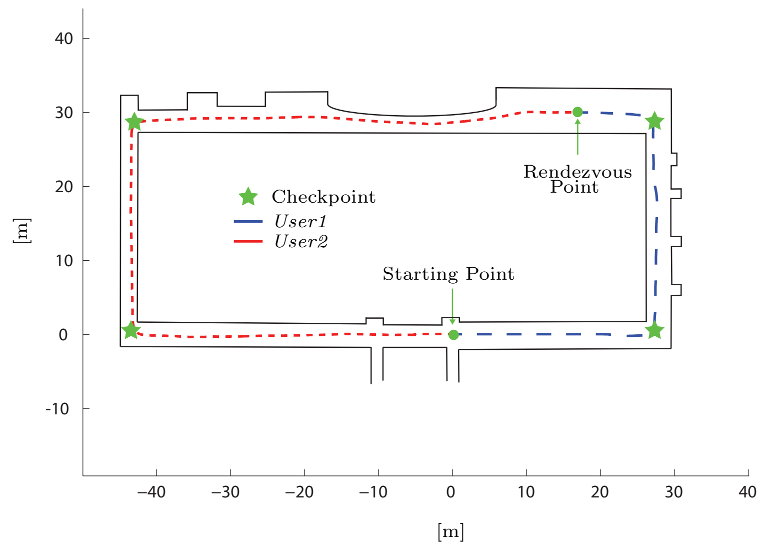


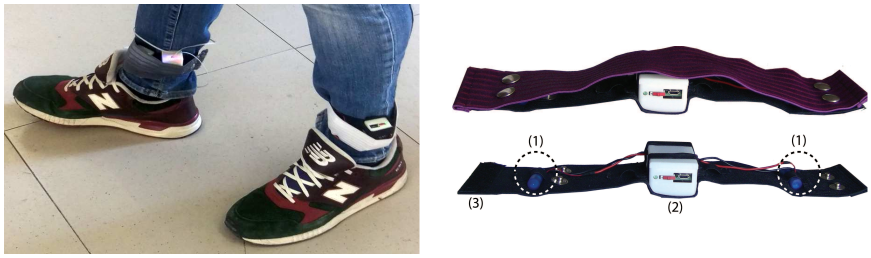
Fig. 1: Cadence is suggested to the users via two vibro-tactile elastic bands placed on the ankles. To reach a predefined point at the same time, users have to adapt their walking pace. The rhythm is updated at specific points in the map, called *checkpoints*. Here, the user also receives direction information through repeated vibrations in the steering side. In this representative scenario, *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. Different rhythms are depicted with different spacing in the dashed line representing the users' path. In this example, *checkpoints* are defined at every corner.

2.2 Experimental procedures

Before starting the experiment, the subjects' average step length at comfortable cadence is estimated. We select two paths toward the meeting point and choose the checkpoint locations. The time to reach the rendezvous point depends on the estimated step length and the average cadence we want to achieve.

In a structured environment it is not difficult to track the users along the path. Thus the arrival at checkpoints can be monitored automatically by the algorithm, which computes the remaining time and distance, and adapts the output cadence.

In an unstructured environment we decide to rely on operators for preliminary experiments. A ghost operator is in charge of following each subject at a 5m distance to supervise the experiment. At each checkpoint, the step length estimation is automatically updated according to the number of steps from the last checkpoint (all the distances are known). This process allows to update the step-cadence reference to reach the destination on time. The trial ends when both users reach the rendezvous point.



(a) (b)

Fig. 2: Cadence cues are provided to the users via two vibro-tactile elastic bands placed on the ankles (a). The haptic bands (b) are composed of two vibrating motors (1) attached to an elastic wristband (3). A Li-Ion battery is in charge of power and an Arduino board controls the interface (2).

2.3 Live demonstration

The experiment becomes self explanatory by recruiting two volunteers to perform the rendezvous trial along different paths. The meeting point is placed at different distances, so that the algorithm will have to estimate different cadence values to provide to the users. Considering the wide space needed to perform this live demonstration, we propose two possible alternatives. Both involve two subjects, who will have to reach simultaneously the meeting point through a physical or virtual path.

In case there is enough space to plan two different paths toward the meeting point, we will perform the trials regularly. Two routes of different (known) length will be defined and the users will have to synchronize to the step cadence suggested by the vibro-tactile interfaces. Before the trial begins, subjects will be required to walk a 30 meters pathway at their own comfortable speed, to estimate the subject's average step-length. The initial desired cadence for each user will be determined by the overall distance they will have to travel and the estimated step length. A ghost operator will follow each subject with a smartphone to indicate the arrival at checkpoints. After reaching each checkpoint, the step length will be refined on the basis of the number of steps walked, and the desired cadence will be updated. During the trial, the suggested cadence will vary depending on the subjects' synchronization ability: users able to keep the external pace will see low variation of the step-cadence, while low synchronization rate will result in bigger cadence variations. The performance parameter will be the difference in time between the two arrivals to the meeting point. If the necessary space is not available, we will simulate the virtual paths with gym-steps: users will climb virtual stairs by stepping on and off, covering a different number of stairs. We will keep track of the trial progresses via display representation of the step count. This method doesn't take into consideration the user's step length, which may be simulated with steps of different height.Cadence will vary with respect to remaining time and stairs, and the users will have to adapt their stepping frequency to the stimulus rhythm. In this case, the trial ends when both the subjects reach the virtual meeting point.

2.4 Conclusions

In this demonstration we present a system to guide users on time to the rendezvous point. It relies on information as path length and subjects locomotion parameters to estimate the adequate cadence and provide it to the user through vibro-tactile interfaces placed at the user's ankles. The users have to adapt their walking pace to the one suggested by the haptic interfaces. The rhythm is updated at specific points, called *checkpoints*, where the user also receive direction information through repeated vibrations in the steering side. In future works, we will further investigate the users adaptability at high-varying frequencies, and how the step-length depends on the provided cadence. Possible application scenarios are human-human and human-robot collaboration, training and rehabilitation.

References

1. Cosgun, A., Sisbot, E.A., Christensen, H.I.: Guidance for human navigation using a vibro-Tactile belt interface and robot-like motion planning. In: Proc. IEEE Int. Conf. on Robotics and Automation. pp. 6350–6355. IEEE (2014). https://doi.org/10.1109/ICRA.2014.6907796
2. Delcomyn, F.: Neural basis of rhythmic behavior in animals. Science **210**(4469), 492–498 (1980). https://doi.org/10.1126/science.7423199
3. Erp, J.B.F.V., Veen, H.A.H.C.V., Jansen, C., Dobbins, T.: Waypoint navigation with a vibrotactile waist belt. ACM Trans. on Applied Perception **2**(2), 106–117 (2005). https://doi.org/10.1145/1060581.1060585
4. Karuei, I., Maclean, K.E.: Susceptibility to periodic vibrotactile guidance of human cadence. In: Proc. IEEE Haptics Symposium. pp. 141–146. IEEE (2014). https://doi.org/10.1109/HAPTICS.2014.6775446
5. Lindeman, R.W., Sibert, J.L., Mendez-Mendez, E., Patil, S., Phifer, D.: Effectiveness of directional vibrotactile cuing on a building-clearing task. In: Proc. ACM Int. Conf. on Human Factors in Computing Systems. p. 271. ACM (2005). https://doi.org/10.1145/1054972.1055010
6. Lisini Baldi, T., Paolocci, G., Prattichizzo, D.: Human guidance : Suggesting walking pace under workload. In: International Conference on Human Haptic Sensing and Touch Enabled Computer Applications. pp. 416–427 (2018)
7. Lisini Baldi, T., Scheggi, S., Aggravi, M., Prattichizzo, D.: Haptic Guidance in Dynamic Environments Using Optimal Reciprocal Collision Avoidance. IEEE Robotics and Automation Letters **3**(1), 265–272 (2018). https://doi.org/10.1109/LRA.2017.2738328
8. Lisini Baldi, T., Scheggi, S., Meli, L., Mohammadi, M., Prattichizzo, D.: Gesto: A glove for enhanced sensing and touching based on inertial and magnetic sensors for hand tracking and cutaneous feedback. IEEE Transactions on Human-Machine Systems **47**(6), 1066–1076 (2017)

9. Lugo-Villeda, L.I., Frisoli, A., Sandoval-Gonzalez, O., Padilla, M.A., Parra-Vega, V., Avizzano, C.A., Ruffaldi, E., Bergamasco, M.: Haptic guidance of light-exoskeleton for arm-rehabilitation tasks. In: Proc. IEEE Int. Symp. in Robot and Human Interactive Communication. pp. 903–908 (Sept 2009). https://doi.org/10.1109/ROMAN.2009.5326057
10. Miyake, Y., Miyagawa, T.: Internal observation and co-generative interface. In: Proc. IEEE Int. Conf. on Systems, Man, and Cybernetics. vol. 1, pp. 229–237. IEEE (1999). https://doi.org/10.1109/ICSMC.1999.814095
11. Riener, A.: Sensor-Actuator Supported Implicit Interaction in Driver Assistance Systems, vol. 10. Springer (2011). https://doi.org/10.1007/978-3-8348-9777-0