Direct Tactile Coupling of Mobile Phones with the FEELABUZZ System

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Abstract. Touch can convey emotions on a very direct level. We propose FEELABUZZ, a system implementing a remote touch connection using standard mobile phone hardware. Accelerometer data is mapped to vibration strength on two smartphones connected via the Internet. This is done using direct mapping techniques, without any abstraction of the acceleration signal. By this, FEELABUZZ can be used for implicit context communication, i. e. the background monitoring of the natural movements of the users themselves or their environments, as well as for direct communication, i. e. voluntary and symbolic signalling through this new channel.
We describe the system and its implementation, discuss its possible implications and verify the system's ability to recognizably transmit different actions in a preliminary user study.

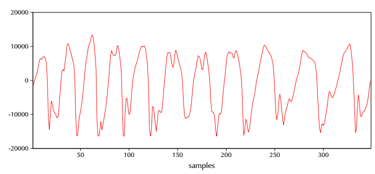
Keywords: mobile devices, wearable computing, haptic display, tactile feedback, mediated communication

1 Introduction

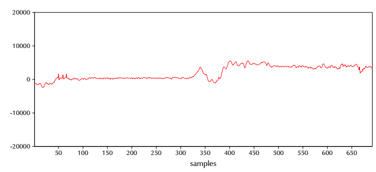
Touch is arguably the most immediate, the most affective, and – when it comes to media – one of the most neglected modalities used for human communication. It can convey emotions and feelings on a direct and primordial level [5,10,18].

We propose FEELABUZZ – a system to directly transform one user's motion into the vibrotactile output of another, typically remote device. Unlike previous work on tactile communication [3] we do so using only mobile phones without any additional gear. This is possible because mobile phones these days almost universally have accelerometers as well as vibration motors which can be used for the sensing of movement and vibrotactile actuation respectively. Mobile phones have the key advantages of not only being widespread to the point of omnipresence but also to usually be worn on the user's body. Furthermore, not having to buy and more importantly to carry around an extra piece of hardware is a property whose importance cannot be overstated. Using phones also makes it easy to integrate the new haptic channel with existing auditory, visual and maybe textual channels, thereby extending the phone's capabilities as a communication device. As we have our phones with us or nearby most of the time, they are well suited not only for *direct communication* but also for *implicit context communication* (e. g. walking or riding the bus; cf. Section 3 for a more detailed discussion of these concepts). Being able to assess a contact's current context could equally be important when it comes to determining a good time to call.

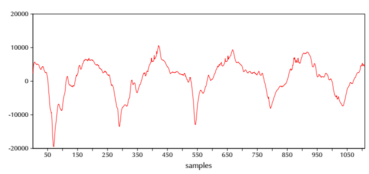
The choice of vibration as an output modality not merely stems from its prevalence on the chosen platform and its availability and unobtrusiveness when carrying the phone in a pocket but also from the fact that movement such as impacts or strokes naturally transforms into tangible vibration in the real world (e. g. footsteps on the floor, multiple persons using one stair rail, someone stirring on a sofa or even the feedback to one's own hand when stroking something).



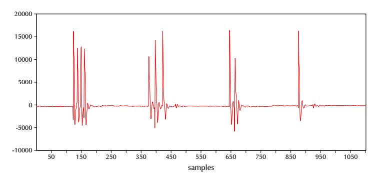
(a) running



(b) relaxing



(c) swinging



(d) hand tapping on the phone

Fig. 1: Accelerometer data of different movements recorded at 100 Hz.

2 Related Work

Heikkinen et al. [10] provide insights on the expectations of users regarding haptic interaction with mobile devices. Their results underline our design considerations. The participants brought up poking and knocking metaphors as well as the idea of a constantly open "hotline" between two participants. Their participants even saw the possibility of the emergence of a haptic symbolism or primitive language, which have been developed during the evolution of the interaction.

O'Brien and Mueller [15] created special devices of various forms to examine the needs of couples when "holding hands over a distance". A main critique of their participants was concerned with the cumbersome and unfashionable design of their devices: "The participants stressed how they wanted a device that was more personal and easy to carry. They desired it to be small enough to fit it in their pocket. One participant noted that she wanted something she could relate to personally" [15]. Furthermore, their users disliked that the special device draw to much public attention.

Eichhorn et al. build a pair of stroking devices for separated couples. Each device has a sensor and a servo which expresses the stroke initiated by the remote device. The device functions as a proxy object to stroke each other over a distance.

A lot of the work already conducted on vibrotactile interaction is focused either on the recognition of haptic gestures or on mapping different cues to haptic stimuli [14,16,2,4,6].

With FEELABUZZ we aim at creating a personal, lightweight and always ready-to-hand haptic communication channel. An earlier prototype of the system has already been presented [12]. In this work we will first discuss aspects of haptic communication, introduce the new FEELABUZZ system and then present and discuss the results of the informal user study.

3 Concepts

The information conveyed by FEELABUZZ can be split into two parts that we call *implicit context communication* and *direct communication*.

3.1 Implicit Context Communication

The most obvious kind of information that is conveyed by FEELABUZZ are the unintentional and implicit movements of the device. These can either originate from the users or from the environment, as already proposed by Murray-Smith et al. [14].

The time-series data in Figure 1 show that different kinds of activities by the users themselves lead to very different acceleration profiles. Likewise, sitting in a driving vehicle will lead to an acceleration pattern that is notably different from those caused by human movements.

Note that none of this has to be detected by pattern recognition software. There are no predefined classes. Instead, the interpretation of many movement patterns is expected to come quite naturally and involve all the rich context information and world knowledge humans have. Additionally, the sophistication of the interpretations can fluently increase with the user experience. As there are rarely clear class boundaries in the real world, transitions between different types of movement can be perceived in all their ambiguity and fuzziness in a near-analogue fashion without the need to make clear distinctions. While regression models could do so as well, the subsequent mapping back to artificial vibrotactile stimuli in a way that allows direct access as well as in-depth learning of subtle features would be a major challenge to say the least. Actually one would have to know and reliably detect any such subtlety in advance before playing it back to a user in an alienated way. Relying on the human's long-evolved ability to interpret rich real-world data streams seems to be a more promising way in terms of effectiveness and a much more interesting way in terms of unintended uses and exploration by future users.

3.2 Direct Communication

Providing people with the possibility to intuitively induce tactile feedback in another person's mobile phone presents a new communication channel that can also be used deliberately in a number of ways. The channel's possibilities for readily understood signals are limited though. Apart from *knocking* to do simple things such as requesting attention, synchronizing or timing pre-decided behavior, or giving short binary feedback, few intentional tactile communication events will be understood by the naïve user. Although there are sophisticated means of communication through such narrow channels, most notably Morse code, we expect that to be employed only by experts and not to become widespread. Instead, we rely on people's ability to develop their own adapted communication strategies using a mixture of implicit and explicit negotiation. Quite complex and effective communication systems can emerge via such mechanisms [7,9,8,17,11,1].

The general lack of interpretation and abstraction on the side of the system enables users to become creative in that they use the system in ways that were not intended by the system designer. It will be an interesting area of future research to see if and how people start to use FEELABUZZ in ways that fall under the definition of *direct communication*.

4 Implementation

4.1 Technology

The FEELABUZZ prototype hardware, which was used for the evaluation, consists basically of two *Palm Pre* mobile phones. On the phones we gather the accelerometer data which is then preprocessed, transmitted and mapped to the vibrotactile actuator of the other phone. The data is transmitted over two direct *Open Sound Control* (OSC) connections [19] between the paired devices. The OSC connection is run over a wireless network connection. OSC is a UDP-based simple push protocol which is widely available in common programming languages. On the device itself we are using the Python programming language to preprocess the sensor data, to connect the devices over the network and eventually to excite the vibration motor.

4.2 Signal Processing and Vibrotactile Mapping

To map the S accelerometer readings $\mathbf{s}(t)$ with $s_i(t) \in [0, s_{max}], 1 \leq i \leq S$ to the vibration module input value $y(t) \in [0, y_{max}]$ we perform a couple of steps.[1] First we compute the magnitude of the acceleration vector:

[1] For the Palm Pre, our prototype hardware, the number of sensors S is 3, s_{max} is 2 and $y_{max} = 100$. The sensor sampling rate was set to 30 Hz.

$$m(t) = \rho\|\mathbf{s}(t)\| = \rho\sqrt{\sum_{i=1}^{S} s_i(t)^2} \tag{1}$$

with ρ being a normalization factor:

$$\rho = \frac{y_{max}}{\sqrt{Ss_{max}^2}} \tag{2}$$

Now an RC high-pass filter is applied to the sensor values with the decay constant $\alpha_h = 0.967$

$$b_h(t) = \alpha_h\Big(b_h(t-1) + \big(m(t) - m(t-1)\big)\Big) \tag{3}$$

which gets rid of the gravitational acceleration and other constant or long-term acceleration influences[2] without losing as much inertia as a simple derivation would.

Subsequently, an exponential smoothing is applied with smoothing factor $\alpha_l = 0.157$:

$$b_l(t) = \alpha_l|b_h(t)| + (1-\alpha_l)b_l(t-1) \tag{4}$$

This is important to give more inertia to the system in a controlled way so that a lot of activity from the sender will add up to give an increasingly strong signal on the receiving end (cf. Figure 2). This turned out to be what best matched our intuitive a-priori expectations of how the system *should* behave.

It has the drawback of levelling out all of the more impulse-like parts of the signal which are a salient feature and also quite important for signalling. To preserve these impulse components as well, we add them back in with a simple kind of spike detection. This also has the benefit of making the system more responsive to quick accelerations as the then-detected spike will kick-start the acceleration motor.

For this we compute the moving average over the last n time steps, defined for any function $x(t)$ as

$$MA_n(x,t) = \frac{1}{n}\sum_{i=0}^{n-1} x(t-i) \tag{5}$$

and check if the high-pass-filtered signal $b_h(t)$ exceeds a certain threshold of $\beta_a = 5$ times the moving average. If this is the case we perform an exponential

[2] When using a sample rate of 30 Hz it is possible to shake the phone so hard that the accelerometers will register a constant acceleration. In an earlier prototype [12] the accelerometers were capable of 100 Hz which was enough to circumvent this phenomenon. To prevent the high-pass filter from eliminating the constant maximum acceleration on platforms that cannot read from the sensors fast enough, it turned out to be excruciatingly inelegant yet appallingly effective to artificially set the sensor value to 0 when a threshold number of successive near-maximum acceleration frames is exceeded.

mapping of the spike signal and add it back to the low-pass-filtered signal with the adjusting coefficients $\beta_{b_h} = 2$ and $\beta_{b_l} = 3$:

$$k(t) = \begin{cases} y_{max} \left(\frac{\beta_{b_h} b_h(t)}{y_{max}} \right)^{\alpha_e} & \text{if } b_h(t) > \beta_a MA_n(b_h, t), \\ 0 & \text{else.} \end{cases} \tag{6}$$

$$y(t) = \min\Big(\eta\big(k(t) + \beta_{b_l} b_l(t)\big), y_{max} \Big) \tag{7}$$

with $n = 5$ and $\alpha_e = 0.4$. The normalization constant η is necessary on some platforms to linearly correct for sensor or actuator sensitivities that are too low. For the Palm Pre we found a value of $\eta = 2.5$ to work well. Finally, the output is cropped to y_{max}.

Figure 2 shows the behaviour of these steps combined. A burst of delta pulses increasingly excites the system and this excitation takes a comparatively long time to wear off. At the same time, the pulses themselves are perfectly preserved and amplified.

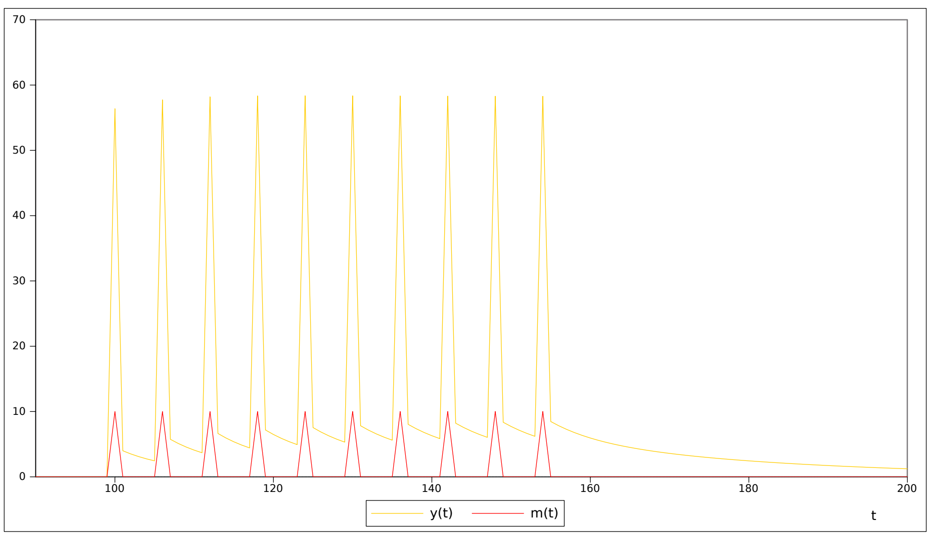


Fig. 2: Filter response $y(t)$ to a burst of delta pulses $m(t)$.

5 Evaluation

5.1 Method

To verify that basic activity types can be distinguished with FEELABUZZ we did a study with 10 participants, 5 male and 5 female. The participants went through the study in pairs who were known to each other. Accordingly there were two phones running FEELABUZZ that were bidirectionally transmitting the acceleration data. As the first step of each trial, the general idea and basic properties of the acceleration-vibration mapping were explained to the participants. Each participant was then given the opportunity to familiarize him- or herself with both phones at the same time to get a better first impression of the mapping. When they both felt familiar with the system, they split up the phones so that both participants had one of them. They were again asked to explore the system until feeling familiar with it. They were then explained the following procedure.

The two participants were separated so that they could no longer see or hear each other. One of them was asked to perform one of three activities while wearing the telephone in their pocket: resting, walking or running. The other participant was instructed to guess which of these activities was being performed, holding the telephone in their hand. This step was repeated ten times before the roles were switched between the two participants. The schedule of activities each participant had to perform was randomly generated in advance and different for each participant.

Finally, the participants were asked to fill in a questionnaire. The questionnaire we used is based on the Computer System Usability Questionnaire (CSUQ) by Lewis [13]. We removed or adapted questions that did not make sense in our scenario and ended up with 12 multiple-choice questions using a 7-point Likert scale. We also added six free-response questions.

5.2 Results

The results of the activity classification can be seen in Table 1 as a confusion matrix. All four misclassifications occurred between the classes "running" and "walking" and only when a participant was first confronted with one of these activities.

Figure 3 shows the responses to four of the questions as histograms. The most favourably answered items were "It was simple to use this system." and "It was easy to learn to use this system.", both of which were "strongly agree"d upon by all participants (average 1.0). The items that scored worst were "I believe I would use this system on a regular basis." with an average of 3.7 (cf. Figure 3) and "This system has all the functions and capabilities I expect it to have." with an average of 3.714.

6 Discussion

The classification results show that it is possible to distinguish different activities using only the FEELABUZZ system. Although it was a task that was fairly easy to solve, the practically perfect performance of all participants is very encouraging. In addition, most users liked using the system (cf. Figure 3). Future studies with more complex and more diverse activities will have to show whether the level of recognition of simple activities holds or if it gets degraded when the users move

		actual activity		
		resting	walking	running
guess	resting	**35**	0	0
	walking	0	**29**	2
	running	0	2	**32**

Table 1: Confusion matrix of the participants' activity recognition using FEELABUZZ

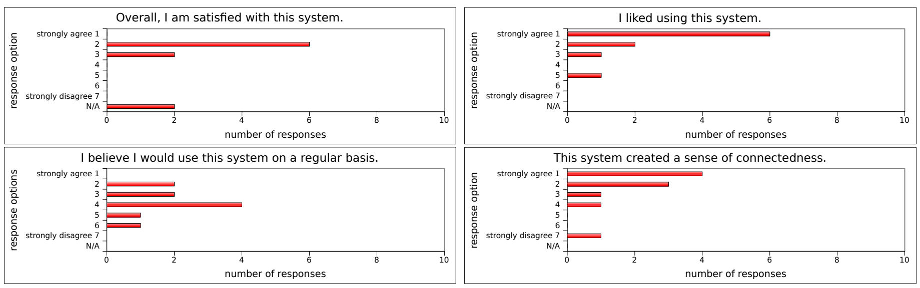


Fig. 3: Responses to four of the questions in the questionnaire. The average values for these questions from left to right and top to bottom are 2.25, 1.8, 3.7 and 2.4.

out of this narrow domain. Even more interesting, though, is the question of whether users will actually accept such a system, how they will use it and what they gain from it emotionally. Longitudinal studies in actual relationships will have to show this but there are some hints already that can be taken from this basic study. Figure 3 shows that the participants had a feeling of *connectedness* to a varying degree. They were more divided, though, on their assessment of whether they would use FEELABUZZ on a regular basis at all. In the free-response questions participants emphasized the aspects *ease of use* and *learnability* that also showed up clearly in the multiple-choice part of the questionnaire. They noted for example that the system was "easy to use", "uncomplicated" and "easy to understand". One participant noted to have "liked the buzzing, it's smooth". Another user mentioned that it was "possible to submit actions without actively operating the device". Some participants found it unlikely to constantly use the system at all time though. One user commented that observation: "I cannot imagine to use it all the time. But it could be handy for those 'what is XY doing right now?' moments."

This feedback to us suggests that there is potential for an emotionally significant connection of people with FEELABUZZ but the right mode of operation regarding the individual timing of the vibration output and the control thereof will be a delicate part of the application design and further investigations.

7 Conclusion

We presented the concept and a prototype of a near-analogue coupling of the accelerometers built into modern mobile phones to the likewise included vibration motors of a remote device to create a feeling of connectedness over a distance. We described a mapping to transmit such acceleration data and implemented it for a pair of *Palm Pre* phones. Furthermore we reported the results of an informal users study. The study showed that users are able to sense if the other person is resting, walking or running just by feeling the activation of the vibration motor.

Our future work is focused on how to run FEELABUZZ on many users' own phones by providing an improved application for download. This will not only make it possible to put future evaluations of our method on a broad basis but also to collect experiences with haptic communication channels in general with a handy device to which the subjects can personally relate and which accompanies them in their daily life.

8 Acknowledgements

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