feelabuzz – Direct Tactile Communication with Mobile Phones

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Abstract. Touch can create a feeling of intimacy and connectedness. In this work we propose FEELABUZZ, a system to transmit movements of one mobile phone to the vibration actuator of another one. This is done in a direct, non-abstract way, without the use of pattern recognition techniques in order not to destroy the *feel* for the other. This means that the tactile channel enables *direct communication*, i. e. what another person explicitly signals, as well as *implicit context communication*, i. e. the complex movements any activity consists of or even those that are produced by the environment. We explore the potential of this approach, present the mapping we use and discuss further possible development beyond the existing prototype to enable a large-scale user study.

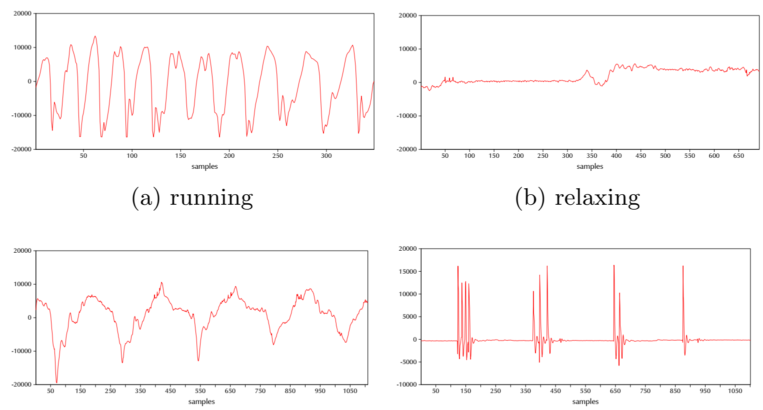
Keywords: mobile devices, wearable computing, haptic display, tactile feedback, mediated communication

1 Introduction

Touch is arguably the most immediate, the most affective, and – when it comes to media – one of the most overlooked modalities used for human communication. It can convey emotions and feelings on a direct and primordial level [5,13,23].

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. Nowadays most mobile phones universally have both accelerometers for the sensing and vibration motors for the actuation of the interaction. Mobile phones have the key advantages of not only being widespread to the point of omnipresence but also to usually be in the direct vicinity of their users. 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) as well.

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 naturally transforms into vibration and similar tactile feedback 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 with 100 Hz.

2 Related Work

Similar approaches have been followed by others. The work of Heikkinen et al. [13] provides 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 [18] 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 about 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". 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 [17,20,2,4,6].

To our knowledge there is no practical work on direct mapping between the accelerometer readings and the vibration motor of a mobile phone. With FEELABUZZ we aim at creating a personal, lightweight and always ready-to-hand haptic communication channel. In this work we will first discuss aspects of haptic communication and then introduce the FEELABUZZ system.

3 The Challenge

Albeit the vibrations today's mobile phones can make are a poor substitute for the actual touch of another person, we believe that the knowledge that it is the very movement the other person is doing just now that makes a user's phone vibrate in a certain way can give them a real feeling of presence and intimacy. Imagine how a piece of clothes our loved one once wore or a letter or the place he or she used to sit can make us feel just because he or she touched it. Often, the less images there are, the more powerful the images our mind will conjure up. Instead of transmitting reality with as much sensory bandwidth as possible, we intend to give people something to build upon and depend on their minds to add in all the details.

Still, how much is there to really hook on to? Figure 1 shows accelerometer data for different activities. It is not necessary to be an expert to distinguish these four sample activities. We are optimistic though that people will become experts in the sense that they will learn even to pick up the comparatively subtle cues that separate the way of movement of close persons from everyone else's way. Provided that a strong social tie is a profound enough motivation to train their sense of touch to achieve this, we think the actual sensitivity of touch is often underestimated [8].

We also included Figure 1d, showing a tapping with the palm on a mobile phone resting in one's pocket, because we think that people will become quite creative once given such a straightforward tool as FEELABUZZ and might for example develop their own signals to quickly inform someone about things without even taking their phones out of their pockets. In this example, you can clearly see that the sensor had been tapped on first four times, then three times, then twice and finally once.

The challenge now is to find a mapping from acceleration data to vibration output that makes it as easy for the users to discern these patterns with their skin as it is to tell them apart visually in the graphs and to deduce the underlying activity in an intuitive way, relying as much on pre-existing world knowledge on part of the user as much as possible.

4 Concepts

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

4.1 Direct Communication

Providing users with the possibility to intuitively induce tactile feedback in another person's mobile phone presents a new communication channel that can be used in many 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 [7,12,9,22,14,1].

4.2 Implicit Context Communication

The other large sector 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. [17].

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 intuitive 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.

5 Implementation

5.1 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 vector of sensor values:

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

with ρ being a normalization factor:

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

Now an RC high-pass filter is applied to the sensor values with the decay constant $\alpha_h = 0.99$

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

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

Subsequently, an exponential smoothing is applied with smoothing factor $\alpha_l = 0.05$:

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

It 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 3). 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.

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 $\beta_a = 3$ times the moving average. If this is the case we perform an exponential mapping of the spike signal and add it back to the low-pass-filtered signal with the adjusting coefficients $\beta_{b_h} = 2$ and $\beta_{b_l} = 3$:

[1] For the Neo FreeRunner, our prototype hardware, the number of sensors S can be either 3 or 6, s_{max} is 2268 and $y_{max} = 255$. The sensor sampling rate was set to 100 Hz.

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

$$y(t) = \min\bigl(k(t) + \beta_{b_l} b_l(t), y_{max}\bigr) \tag{7}$$

with $n = 5$ and $\alpha_e = 0.4$. Finally, the output is cropped to y_{max}. For our prototype platform, the Neo FreeRunner (see Section 5.2), we noticed that values of $y(t) < 30$ are not noticeable so we set them to 0 to not unnecessarily strain the battery (not included in Equation 7 and Figure 3).

Figures 2 and 3 show the behaviour of these steps combined. The step response in Figure 2 is shown with the intermediary steps $b_h(t)$, $b_l(t)$ and $k(t)$. The high- and low-pass characteristics of $b_h(t)$ and $b_l(t)$ can clearly be seen. The output signal $y(t)$ subsequently shows an immediate response as well as a strong inertia that can be configured independently from $b_h(t)$. $y(t)$ and $k(t)$ are clipped to y_{max} which distorts their shape.

In Figure 3 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. They are also clearly high-pass filtered as made apparent by the downward spikes that help them stand out in noisier signals.

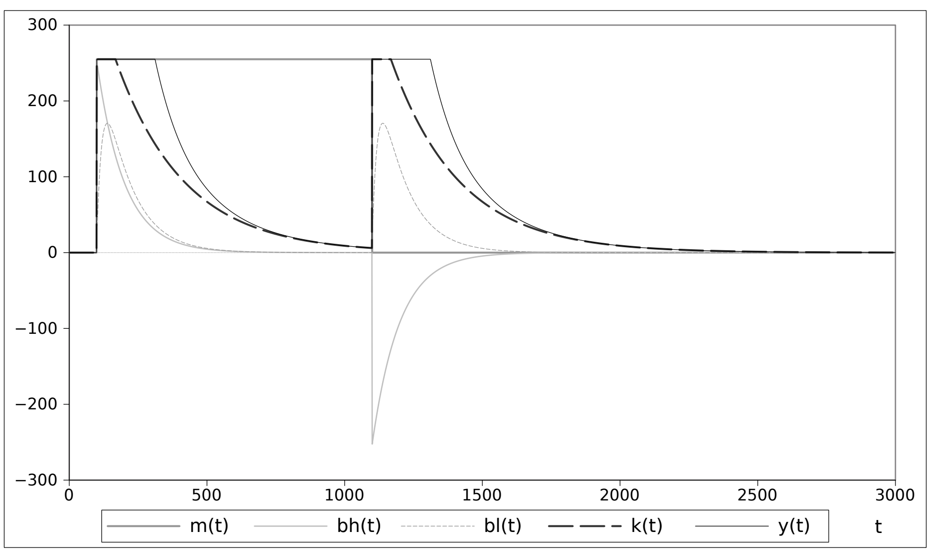


Fig. 2: Step response to the rectangular signal $m(t)$.

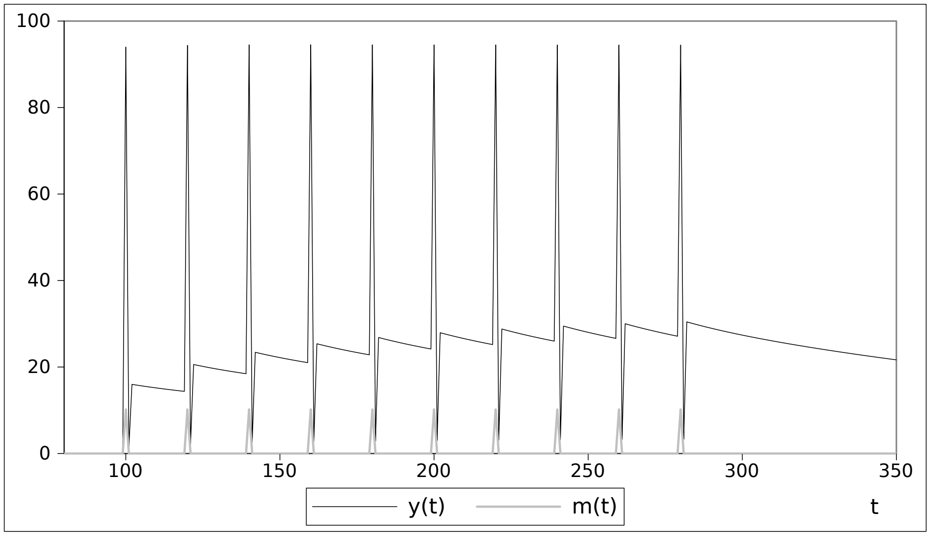


Fig. 3: Filter response $y(t)$ to a burst of delta pulses $m(t)$.

5.2 Technology

The FEELABUZZ prototype hardware consists basically of two paired mobile phones. On the phones we gather the accelerometer data which are then preprocessed, transmitted and mapped to the vibrotactile actuator. Our prototype system was developed using the Neo FreeRunner devices (GTA2)[16] running Openmoko SHR [15].The communication is transmitted over two direct *Open Sound Control* (OSC)[24] connections between the paired devices. *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 acquire the sensor data and preprocess it, connect the devices over the network and then excite the vibration motor. The prototype showed that different activities as illustrated in Figure 1 could be distinguished. The tapping was recognizable as well as other activities that could well be separated from each other. To see whether these findings hold true for a wider range of users with different backgrounds, we are working on a large-scale user study. For conducting this evaluation we need to distribute FEELABUZZ as a conveniently downloadable application on a common mobile platform. The Neo Freerunner devices served well for the prototype system as they provide a very accessible platform, but they are already quite out-dated with respects to their hardware and not very common these days and therefore not well-suited for the evaluation. The Android [10] platform on the other hand seems to be the perfect match for our needs: it is widespread, it features multitasking and an *Application Store* [11] for the easy distribution of the software.

We designed a concept for a new application which we are working on right now.

5.3 Application Concept

A sketch of the future interface can be seen in Figure 4. The application shows a short activity level history from all available contacts. The contact overview serves as a visual representation of the users' accelerations. Thereby a user can quickly see which contacts show interesting activity patterns at any time. The visual overview also serves as a *chat room* in which all users can simultaniously see and react to each other's activity patterns. It would also be easy to discern similar acceleration patterns arising from joint activities (e. g. sitting in the same accelerating vehicle or doing sport together). An additional audification of the current history upon selecting it might also be useful for an eyes-free interaction. Preliminary tests indicate that such acceleration data can be quite characteristic when played back as a short sound snippet, too. The history can also function as an activity footprint, although surely this raises privacy concerns which need to be addressed. The users can therefore also use the contact list to configure their privacy settings. They could for example decide to which contacts they want to transmit their activity or maybe even transmit a random baseline activity that does not reveal that activity transmission has been disabled.

In summary, the new application is designed to enable the users to dynamically manage their haptic communication channels both on the receiving as on the sending end using one contact list style interface. The application will support the user in:

- managing contacts and permissions
- providing an activity overview
- providing a *haptic chat room*

This among other things calls for a new network infrastructure. XMPP [21]/TCP is used as the transport layer for the communication between the devices. XMPP provides most of the needed features (such as dynamically connecting the users' phones, managing their contacts and sessions). More functionality is provided by XMPP's publish/subscribe extension [19]. XMPP also has other advantages over OSC. The current implementation depends on a network connection without too much fluctuation in the amount of delay because each sensor reading is immediately transmitted and haptically displayed. Any jitter in the amount of lag will thus translate into stretching and contracting of the activity curve along the time axis. A fixed delay probably won't be that much of a problem as it only becomes noticable in a decreased reaction time or when synchronizing with other communication channels. The obvious fix for the distortion problem will therefore be a buffering of a certain amount of data before sending it in packets. This will introduce a certain amount of extra lag but on the other hand will compensate for any fluctuations up to this deliberate delay. It will also have the effect of reducing the network load by vastly reducing the amount of data packets that have to be sent.

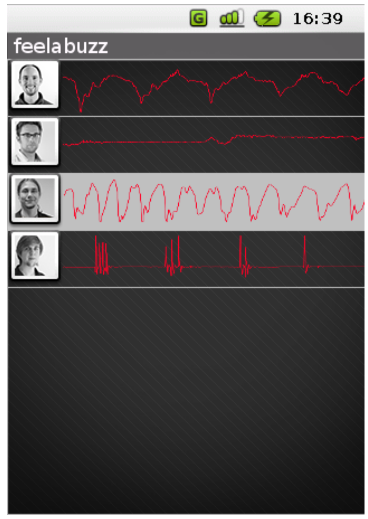


Fig. 4: Concept of a FEELABUZZ Android app.

6 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 that can recognizably transmit such acceleration data and implemented it on a pair of prototype phones. By adapting the sensitivity of the system to the signal's energy level, even minute movements can be transmitted without saturating the output too quickly. Our prototype algorithm can even transmit small rotational movements of the device. Finding a good adaptive algorithm that can fade between the sensitive and the current mode is a very interesting perspective.
Furthermore we presented the concept of the future application which will serve as a basis for our large scale evaluation. Enhancing the usability of the interface and enabling a user's whole social network to be haptically interconnected is another important step. To support users in the setup of the haptic communication channel we designed a user interface which provides a short visual history of the motion of their contacts (Figure 4). Contacts can be tuned into by just selecting them from the list. The design envisions either this one-to-one or a many-to-many mapping similar to a group chat. The above-mentioned move to the XMPP infrastructure will support the dynamic management of the haptic communication channels. Furthermore, XMPP's central routing is needed to connect users in different networks and behind NAT routers which are quite com-

mon at home. The aim is to get to run FEELABUZZ on many users' own phones by providing an improved application for download. This will not only make it possible to put the evaluation of our method on a broad basis but also to collect experiences with haptic communication channels in general with an omnipresent device to which the subjects can personally relate and which accompanies them in their daily life.

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