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Add-on 5kHz Inductive Link for Mobile Phones Using Audio Port

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Abstract—**Today's mobile phones provide several wireless interfaces, both for local and for cellular connectivity. What has been lacking, however, is connectivity to the de-facto standard wearable heart beat sensors using a 5 kHz inductive link. We have developed, for mobile phones, a simple add-on device (hardware) that can be plugged to the audio port of a mobile phone, and simple add-on software for Nokia N900 phone, together capable of reading the heart beat signal. Possibilities exist for other use-cases of wireless sensor networks using the presented receiver.**

inductive link, mobile phones, body area networks

I. Introduction

Wireless body area networks (BAN) have been in the market for almost three decades. In the late 70's, professor Säynäjäkangas of University of Oulu invented the wireless heart beat monitor for fitness applications [1]. The idea involved a heart pulse detector electrode belt around the chest of the user and a display unit in form of a wrist watch. The sensor unit sent a magnetic pulse on 5 kHz carrier frequency every time the heart beat was detected, and this pulse was detected by a coil on the wrist unit. The short range of about a meter was initially enough to distinguish the sensor, thus no data protocol was needed. Later on, since the technology got more use, the devices have had an overhearing problem and Polar Electro has added more pulses to encode the message.

For a single use-case a wrist-top user interface unit with a peripheral sensor is enough. Mobile phones, however, have become the device carried along by most of the world's population, providing a user interface, both local network and internet connections, and capability to run applications.

The price and power usage of digital wireless networking solutions have decreased while the versatility has increased. Need for standardized solutions to decrease cost by mass production has resulted in the emergence of general-purpose technologies. There are plenty of consumer use-cases for mobile-phone-centric WBAN, ranging from cameras to GPS devices, headsets, and heart beat sensors. Multi-vendor solutions are preferable for many use cases to make it possible to use various peripheral devices with the same central node. This results in a drive for standards, such as IEEE 802.15, which act as a basis for many radio technologies.

A mobile phone includes nowadays several wireless transceivers. For example, a Nokia N97 phone has Bluetooth, IrDA, WLAN, and a low-power FM transmitter for local connectivity, in parallel to GSM/WCDMA long-distance connection, and GPS as well as FM receivers. There also exist commercial mobile phones, e.g. Nokia 6212, which include a 13.56 MHz near field communication (NFC) reader, providing practically touch-range connectivity. The connectivity provided by a mobile phone can be used both for local and remote networking and for powering passive devices, enabling, e.g., health and fitness applications [2]. On the other hand, due to the small size, power supply constraint, and multitude of radio interfaces, it is difficult to include to a mobile phone yet another electromagnetic transmitter/receiver, e.g. 5 kHz inductive link, incompatible with the existing ones. This handicap has – up-to-date – prevented the inclusion of ZigBee (IEEE 802.15.4) or ANT [3] radio, as well as connectivity to practically standard 5 kHz heart beat sensors. The personal area connectivity provided by mobile phones, Bluetooth, has had serious limitations with regards to low power peripherals, e.g. these button-cell battery-powered sensor nodes.

Therefore, there clearly exists need for a simple pulse connection, such as heart rate. For simple heart beat sensing applications, such as sports, using Bluetooth is overkill. For that reason, most of the wrist-top heart beat meters are still based on 5 kHz inductive link. Also some other sports sensors, such as GPS speedometers (Polar Electro G1) and step counters (Polar Electro S1), use the same 5 kHz technology.

In addition to wireless receivers and a wired digital USB (or similar) port, mobile phones include typically an audio port, which supports standard analog audio. As the 5 kHz carrier frequency is well in the audio range (12 Hz–20 kHz), it is found possible that a simple tuned coil circuit with an amplifier could be connected to mobile phone's audio port. Thus, the pulse could be detected and processed by audio circuits of the phone. Actually, it has been proposed that the existing audio-range coil circuits on mobile phones (e.g., speaker) could be used to catch the 5 kHz signal for processing [4], requiring some hardware modifications within the phone, though.

II. Architecture

Due to its ubiquitous nature, mobile phone is a natural interface candidate to body area networks. Our architecture is

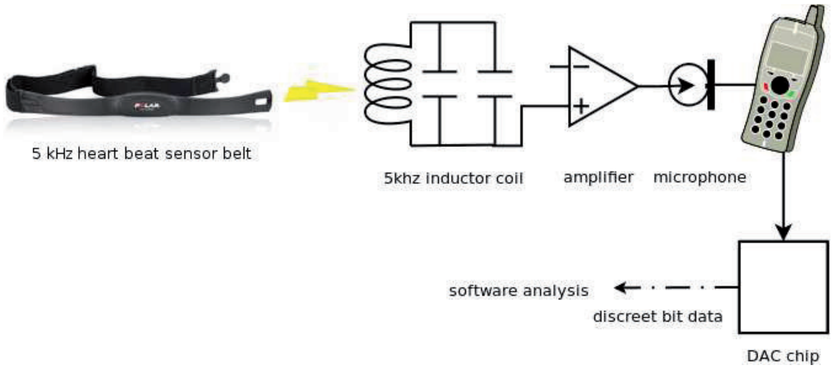

Figure 1. Implementation design for heart beat sensing

based on a mobile-phone-centric approach to ambient intelligence for health care, wellness, and fitness applications: personal mobile phones provide trusted intelligent user interfaces and wireless gateways to sensors, networks of sensors, local networks, and the Internet [5].

We propose a mobile-phone-based architecture, which includes the personal mobile terminal with access to wireless sensors in near proximity. Our architecture defines three different hardware entity types: mobile phones, high-bandwidth wireless sensor devices, and low-power wireless sensor devices. For the high-bandwidth sensor devices, Bluetooth is the natural networking solution, as it is provided in most mobile phones. The applicability of Bluetooth is extending to the low-power range by Bluetooth Low Energy, part of the Bluetooth 4.0 standard [6]. For the very low power applications, where also the sensor data occupies a very low bandwidth, the 5 kHz inductive link is useful, and can be provided by some add-on electronics.

III. Implementation

Our proof-of-concept implementation consists of two parts. The first part is a hardware chip which functions as a radio receiver and the second part is receiver software to decode and analyze the radio signal. Conversion from analog radio signal to software recognizable binary format is done by the already existing audio chip. The whole setup is shown in Fig. 1.

Virtually every mobile device has an audio chip built inside. These audio chips have two functions, to play and record audio. Audio chips universally have TRS connectors for playing and recording audio. These connectors are used to connect microphone, external audio devices and speakers to the audio chip. Any sensed signal is directly converted to audio frequency band and transmitted in identical analog form using an electromagnetic field. Thus, the transmission signal is always analog. To translate the received analog audio signal to computer recognizable digital format the audio chip has a analog-to-digital converter (ADC). This converts incoming analog transmission to digital format, as well as outgoing digital audio signal to analog audio signal (DAC).

A. Hardware implementation

The radio receiver for 5 kHz is simple and well documented [7]. The inductive signal is captured by a small coil which is a ferrite core inductor. This coil functions as a 5 kHz resonator and with capacitors it provides some front-end band-pass filtering. The chip includes one integrated circuit, an LM324N operational amplifier. In our proof-of-concept setup, the amplifier needs an external power source. We are using a normal 9 V battery. The receiver electronics has a normal TRS (for computer soundcards) or TRRS (for mobile phone audio input) audio plug. The receiver circuit design is shown in Fig. 2. In addition to the receiver we have also included speaker and sound amplifier inside the hardware implementation. With a simple switch we can turn the speaker system on for easier debugging. With this we can actually listen to the 5 kHz signal as an audible sound..

In radio communication we need to use digital-to-analog converters to transform the analog radio signal to computer recognizable digital format. This concept has already been introduced for educational purposes [8]. The conversion and the chip are almost the same with the audio chips. By using the already existing ADC chip we can build a cheap and easy receiver for low bandwidth radio. In this paper we are focusing the recording side, i.e. the 5 kHz receiver. Our test environment is a normal PC laptop and a N900 mobile phone with integrated soundcards. Integrated soundcards are very typical in low-end consumer laptops. The maximum sampling rate of this soundcard is 44100 samples per second. The bit depth of samples is 16 bits, thus the resolution of wave is quantized to 65536 steps. To capture the 5 kHz signal we need an antenna coil and an amplifier to get strong enough signal for the soundcard to recognize [9].

For testing our implementation we acquired a Polar heart beat sensor (Wearlink 31 Coded) and a Polar G1 GPS tracker. Both devices use 5 kHz frequency to communicate with the bundled wrist-top computer (e.g. Polar FT60). We will demonstrate that our implementation can successfully receive and decode the protocol sent by this kind of device.

B. Software implementation

Almost any library for audio programming could be used for this radio input. We selected GStreamer [10] as our audio

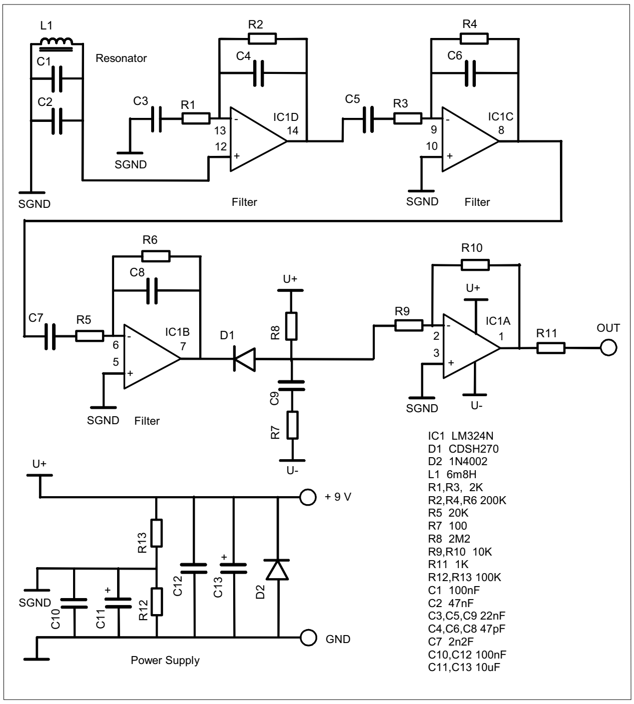

Figure 2. Receiver circuit plan with component list

library due to its support for both desktop Linux and Maemo mobile phones. We use GStreamer API to record audio from the audio jack. Our add-on inductive link hardware described at the previous section is connected to the microphone jack. Our software functions as a software radio. It captures all data coming from the add-on circuit. An example of a received signal shown in our application is illustrated in Fig. 3.

The receiver software retrieves audio stream real-time from the sound card. Audio stream has to be retrieved as a raw data without any additional audio processing. Normal audio processing would remove information needed by our software radio: click sounds would be suppressed as noise, but for this type of received signal processing the actual data is carried in these small pulses.

Our sampling rate was set to 22050 samples per second to decrease processing time. Maximum rate would have been 44100 samples per second, yet this would clearly have been overkill for our purpose. Receiver software compresses the received data even more by averaging 50 samples to one. Thus our real receiving data rate is 441 samples per second. Bit depth of samples is 16 bits. The receiver software maximum theoretical data rate is 882 B/s. This is clearly sufficient because our test transmitter’s maximum rate is less than 2 B/s.

The actual interesting data is convoyed via prominent hearth rate pulses. Existing pulse is decoded as binary "one" and nonexistent as binary "zero". The strength of the impulse does not contain any actual information for us but contributes to reception sensitivity only. The receiver software has to filter interference and recognize impulses from the radio signal. The receiver software has two rules for recognizing the impulses. Impulse has to have large enough deviation from the average noise level, and there should be an ignorance window after a recognized impulse. The latter is to clear off heart beat coding, but if there is need for coding, or if more data types than just heart beat pulses are being transmitted, then the ignorance window can be omitted.

In the graph (example shown in Fig. 3) the peaks represent the signal. Just to get the peaks we filter 99% of the data out. Sample is considered a peak only if belongs to 1% of the largest data group in the past receiving window. We managed to get good results with filtering threshold set to five times to the mean value. Another rule is to wait for a small delay after recognizing an impulse. This ignorance window is set to 50 ms to filter out everything else than heart-beat-generated impulses. The recognized impulses are recorded in received data window.

The received data window is given to a protocol module which tries to recognize the incoming transmission. Only heart rate monitor device recognition was fully implemented for our proof of concept paper. The module tries to decode the data. The module compares received reference values to database. If the reference values are within a specified range we assume that received data is compliant to the given protocol. To support multiple devices we need modules to support their respective protocols and database of reference values. With Bayesian probability we can make decision which protocol

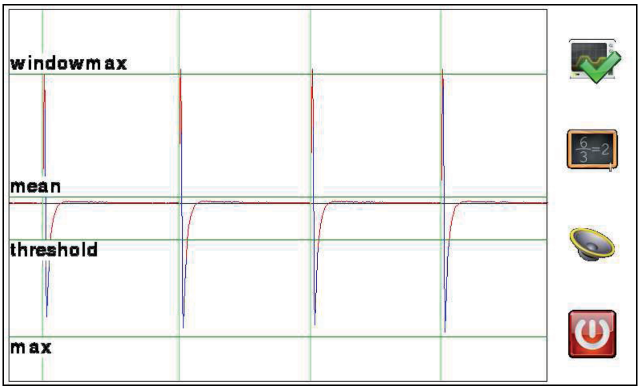

Figure 3. Received signal shown in the receiver software.

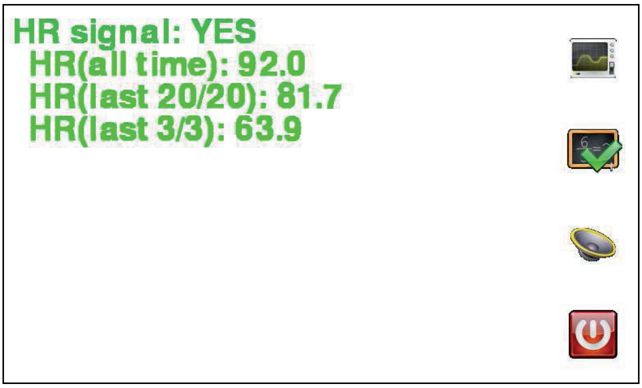

Figure 4. Signal recognized and hearth rate protocol decoded by receiver software.

module to use to decode the incoming transmission and thus recognize which devices are within range.

Adding a module to support new devices is simple for the device manufacturer or if the protocol is known. Our module recognizes the Polar Wearlink 31 heart rate signal. Also there might be additional operations the module has to perform; e.g., our heart rate module calculates the moving average of the heart rate and keeps record of the received heart rate. This operation can be seen in Fig. 4. This module also calculates the reliability and strength of the incoming signal.

During our analysis we realized that the input sensitivity of the sound cards differs notably. The received signal strength might be ten times higher in the best sound cards compared to the worst. The receiver software uses a dynamic algorithm to normalize the results. The graph drawn in the receiver software can be adjusted by hand for more accurate study of the signal.

Our implementation was able to receive data from both of the real transmitting devices, the heart rate transmitter and the GPS tracker. Knowing the protocol of the heart rate transmitter, we were able to develop a software radio module to decode the data protocol. Our receiver antenna and sound card DAC have resolution and sensibility which easily exceed the official wrist-top computer provided together with the transmitters. Distance between the transmitter and our receiver could well be over two meters and we could still get the signal. The resource usage of our software is minimal. Processing data with a rate less than 500B/s is no trouble for modern CPUs nor is the memory usage.

During the analysis we perceived a considerable amount of interference indoors. We observed the source to be almost any electrical device, yet we identified computers as a source of a considerable amount of leaking 5 kHz radio signal. Modern smartphones do the same, yet aligning the antenna coil correctly with the device we could minimize the interference. Also radio insulation between the receiver antenna and the mobile device could be constructed.

IV. Conclusions

Today's mobile phones provide a multitude of wireless interfaces, such as 3G/WCDMA or another cellular network, Wi-Fi, Bluetooth, NFC, and FM. What is missing, however, is an interface to the common wearable heart beat sensors using the 5 kHz inductive link. We have found, however, that it is feasible to add this functionality to a mobile phone simply by developing a cheap and simple appliance that can be connected to the common duplex audio (wired headset) port available in most mobile phones. Also some software is needed to use the phone's audio circuitry to catch the 5 kHz pulses from the audio input, which is also found feasible as the frequency is well within the frequency range of sound.

We have implemented the electronics and software to a Nokia N900 phone. The hardware is not phone-platform-specific, but the software naturally is. The implementation is, naturally, not limited to receiving just the signal from wearable heart beat sensors. Any low-bandwidth sensor could use this communication method. For example, Polar Electro uses the 5 kHz inductive link to transmit data not only from their T31 heart beat sensor, but also from G1 GPS receiver and S1 step counter. Thus, the 5 kHz inductive link could be the solution for wireless connection to any low-power low-measurement-rate sensor with low data bandwidth. Considering the extremely low power use of e.g., heart beat sensors using 5 kHz pulses for communication – they work more than a year with a single button-cell battery – this might be an attractive solution, if the sensor itself does not use much energy.

Simple 5 kHz analog interface presented in this paper could be used as a low-cost unidirectional sensor interface with other sensors – without needing to add a dedicated circuitry for data reception. Since the payload is transmitted at a very narrow bandwidth, this is easy to separate from normal voice audio signal, and operation could be possible even with simultaneous phone call active. Also, the current approach could find many uses outside mobile phone industry, for example among mp3 players often used for enjoying music while exercising. By minimizing additional circuitry and hence adding a low additional cost burden this implementation could even be used on board very low-cost handsets, where total cost of bill of material is extremely critical.

Acknowledgment

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