D4.3 – Stationary Hardware Readiness Report

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Deliverable 4.3	Executive Summary
The KNOTS project can be generally divided to a software and a hardware part as shown on Figure 1 in Section 2 of this deliverable. The hardware part consists of mobile and stationary part. This document contains a short summary of stationary hardware development for the KNOTS system.	

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1. Introduction

The KNOTS project can be generally divided to a software and a hardware part as shown in Figure 1. The hardware part consists of mobile and stationary parts. This document contains a short summary of stationary hardware development and its outcome.

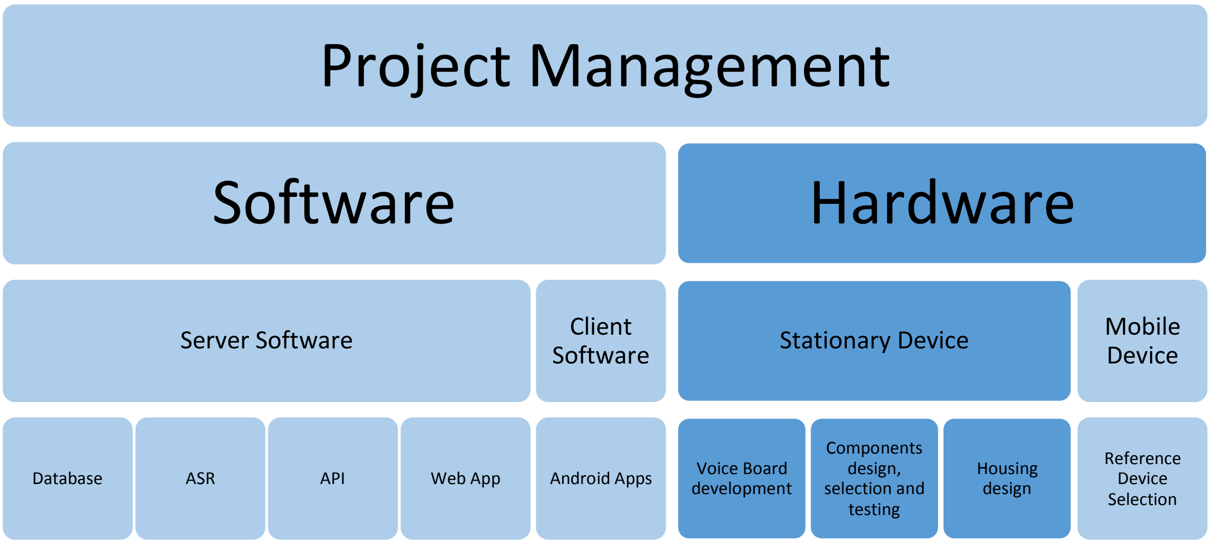

Figure 1: KNOTS project structure

2. Stationary device description

As described in the KNOTS Deliverable *D4.1 ("Specification sheet for end-devices and available components")*, the stationary device is based on Android with a (custom) KNOTS application installed on it. The application part has first been described in Deliverable *D2.2 ("Concept for graphical Design Implementation")* and later changed according to the outcome of the user evaluations as described in Deliverable *D2.3 ("Evaluation Report of the 1st Evaluation")* and Deliverable *D2.4 ("Evaluation Report of the 2nd Evaluation")*. As software is not the focus of this document, only the hardware part is described in this document.

The device itself is an ARM based touch-screen Android device (shown in Figure 2) made of a mix of commercially available and custom-designed components. The hardware design mostly followed the specifications described in Deliverable D4.1. However, several design changes had to be made during development and testing of the device.

- The power supply had to be adapted due to problems with high currents required to power the device. Such (high-current) appliances require more big / heavy and more expensive power adapters, thicker cables and generate more heat which has been adapted now in the KNOTS device. Initial device supply voltage of 5V DC was raised up. An additional DC/DC step-down adapter had to be built into the device for supply of components that require 5V DC.
  In addition to this, a battery charging controller was also adedd to the internal power supply. This is a small but very important part of device. It controls charging/discharging of the battery and prevents damage of battery, caused by overheating, overcharging or other similar conditions.
  The speaker-amplifier is now powered by higher voltage as before and, thus, requires several times less current as the one used in the first prototype. This improvement decreases heat problems and makes it possible to use thinner (thus lighter and cheaper) wirings.

Figure 2: stationary device appearance

- Microphones are now integrated in form of a PCB microphone-array (see also Sections 4.1 and 4.2). Integration of the newly developed microphone array required some housing adaptation on one side, but resulted in easier and more precise mounting on the other side. The signal processed by the microphone-array now gives much better input signal, which is very important for speech recognition. A special voice board, developed by FHG as part of this project, connects microphone array with motherboard (see also Section 4.1 for details).

All these changes required also some adaptation of the housing but it's appearance still complies with the initial plans.

Figure 3 shows the general device architecture, with power supply wirings in color and data connections in black. As it can be seen that there are multiple voltages in use - mostly 24 V (red) and 5 V (blue). Yellow color represents electricity, provided by the battery.

Other parts of the device fit the specifications described in Deliverable D4.1 *("Specification sheet for end-devices and available components")*, so they are not discussed again in this document.

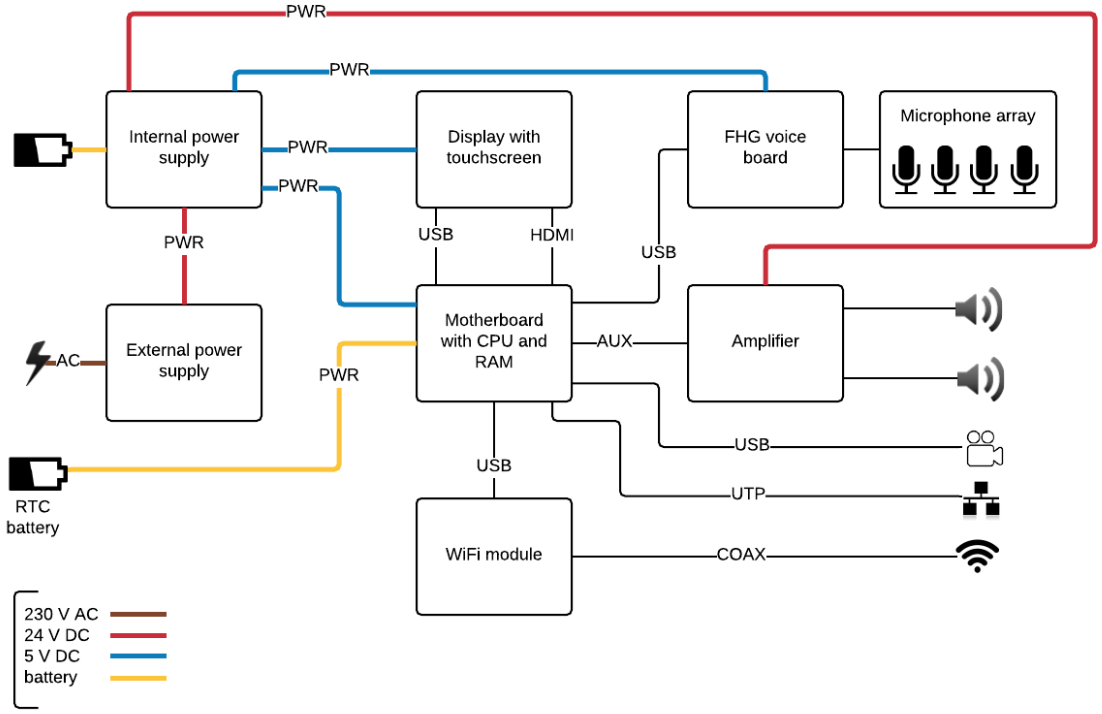

Figure 3: Device architecture

3. Device specifications

Device final stationary KNOTS device has the following specifications:

Display: 9" 1280 x 800 px TFT LCD
Touch Screen: Capacitive Multi-touch
CPU: 1.8 GHz Cortex-A15 Quad-core
RAM: 2GB LPDDR3
Storage Slot: Micro-SD
Power Input: 15-25V DC max 2 A
Multimedia: camera, loudspeaker, microphone array with DSP
Housing: white plastics
Connectivity: Wi-fi, Ethernet
Operating system: Android 4+

4. Deice Development

Stationary device development process began with determination of requirements of device functionality (Knots application, voice recognition, loud speakers, connectivity, etc.) According to these requirements, approximate device specifications were written. Work was done by the KNOTS partners as follows:

- development of speech recognition related hardware (FGH)
- selection and development of other components (ETK)
- components integration and final testing of an appliance (ETK)

4.1. Speech Recognition Related Hardware

At the beginning of the Knots project, it was already clear that a standard (mono) microphone will not be able to provide a quality of sound required for a good speech recognition system. So a decision was taken to develop a special digital signal processing board, together with a special printed circuit board (PCB) microphone array.

Audio signal akquisition for the stationary KNOTS system is done using multiple microphones (a microphone array). Like humans are capable of listening to a specific spatial direction with their two “sensors” (i.e. ears), technical systems with multiple microphones are able to suppress acoustic disturbances which do not come from a defined target direction. In the KNOTS scenarios the target sound usually is a speaking person in front of the array while “disturbances” can be everything like switched on radios, TVs, sounds from open windows, etc.

The KNOTS audio interface contains a nested microphone array and a signal processing unit which provides flexibility for different connections (see Figure 4). For a broad frequency range, 6 microelectromechanical systems (MEMS) microphones with digital I^2S-outputs (Inter-IC Sound) are placed with different spacing on the PCB. Via a flat cable the nested line array can be connected to the signal processing unit, which supports up to 8 channels to the I^2S connector. The signal processing unit contains a digital signal processor (DSP) with universal serial bus (USB) connectivity and stereo analog audio output. The USB interface supports USB Audio 2.0 with special drivers by Thesycon for windows. Other operation systems such as Linux / Android also support this USB Audio connection.

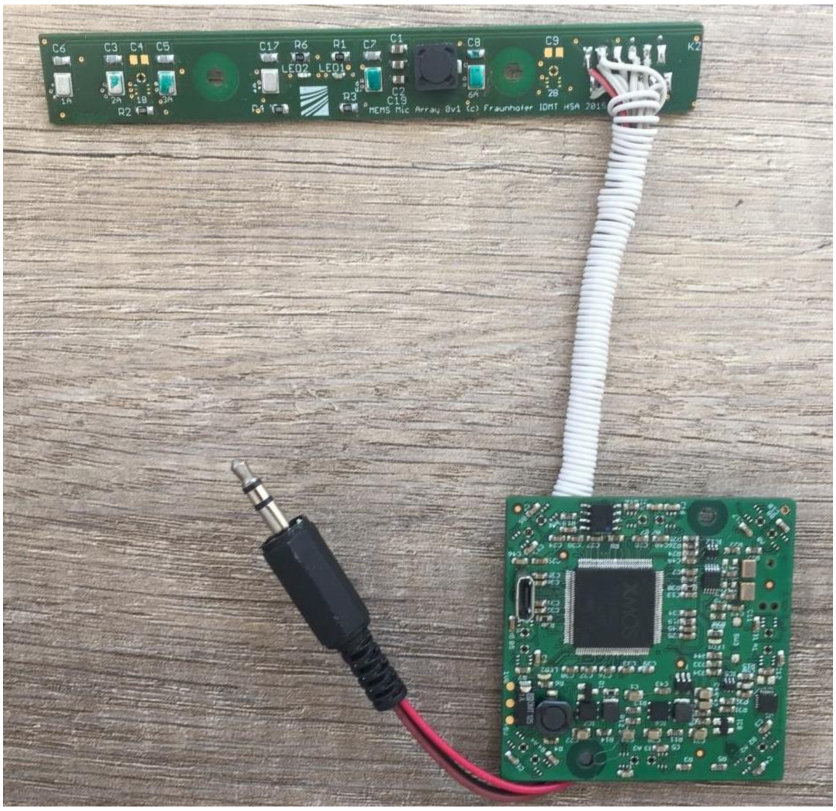

Figure 4: Audio processing unit (microphone array (upper part) and signal processing unit (lower part))

A fixed point XMOS processor (XE-Series) is used as the DSP, which has multi-core architecture divided on 2 tiles. One tile is replaced for doing the USB interface and the other contains algorithms for audio sample transfer and digital signal processing (cf. Figure 5). The digital multichannel microphone signals are transferred to the audio tile to convert the signal to digital audio samples. Using these fixed point audio samples some (further) noise reduction algorithms can be applied in the future if needed (in addition to the beamformer described below). The processed samples are transferred to both, USB host and D/A converter (stereo analog output).

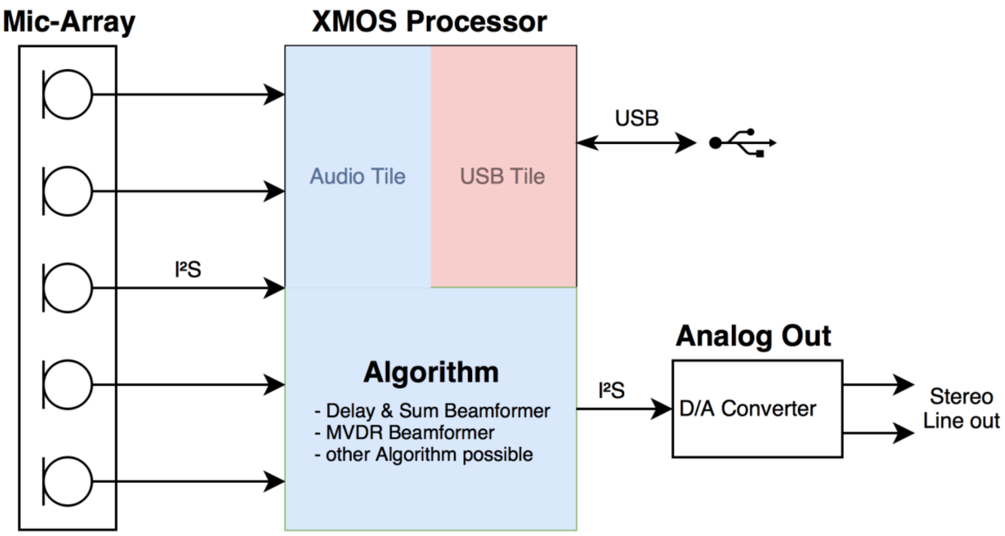

Figure 5: Audio Processing Unit (signal flow graph)

One established algorithm applied in the KNOTS audio front-end is the so called minimum variance distortionless response (MVDR) beamformer which is a method for reduction of disturbing (background) noise and does an acoustic focus on the desired speaker position while other signals around are attenuated. With this method the SNR will be increased and, by this, better speech signal quality is obtained, both for human listeners as for the automatic speech recognition engine. The performance of the beamformer was tested by simulations and test measurements.

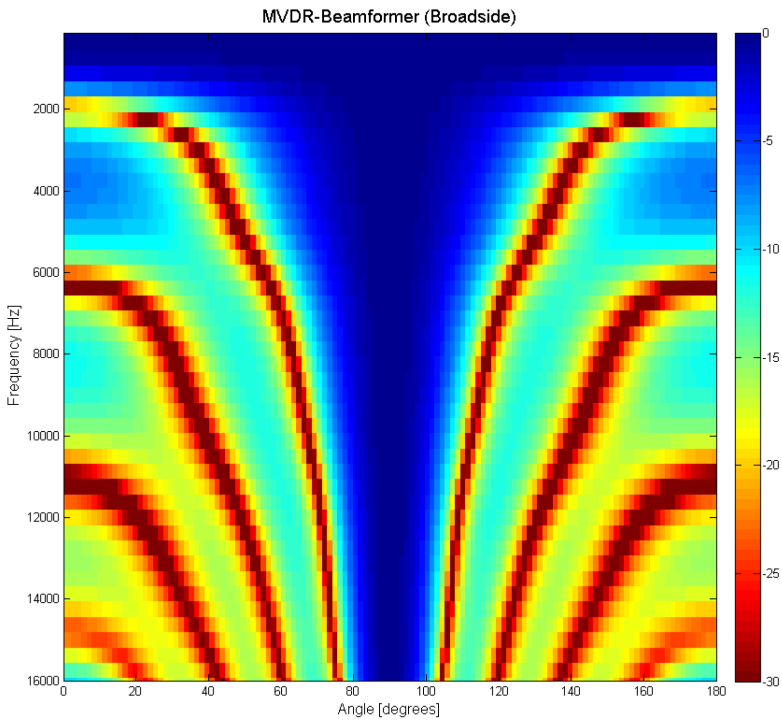

Figure 6: Beam pattern of array simulation for different angles and frequencies.

The MVDR beamformer is designed for a broadside array application (90° steering direction). Figure 6 shows the beam pattern simulated for different angles (x-axis) and for all frequencies (y-axis). The implemented MVDR beamformer assumes a diffuse noise field (which is a typical assumption for indoor use) for which signals coming from the “look direction” of 90° are not distorted (blue color in Figure 6 corresponds to 0 dB suppression which is a product of the signal with unit response from that direction, i.e. no suppression). All other sound angles from which signals are picked up by the microphone array will be damped (at least for frequencies above 150 Hz). The main lobe at 90° and the damping of the side lobes depends on the dimensions and geometry of the microphone array. With this hardware configuration a sidelobe damping about -6dB or higher can be reached.
The DSP allows to include other noise reduction algorithms to increase the speech intelligibility and the audio quality in case they might become necessary for follow-up developments of the KNOTS system (e.g. acoustic echo cancellation in case the KNOTS system should be used as a hands-free device later by the users).

4.2. Audio Amplifier

The easiest way to support sound input (microphone) and output (speaker) is to use a headset (or its’ equivalent). However, a “hands-free” capability may be demanded later for this device. Such functionality requires much louder signals to be uttered by the loudspeakers and more sensitive microphones.

All of generally available chips or boards with sound output capability provide enough power to drive headphones, but the speaker built into the KNOTS device needs to be much louder. There are two main reasons for this requirement:

- a stationary device is located much further than headphones (typically min. 1 m vs. 1 cm)
- elderly people, who are the target population, have worse hearing

In order to gain enough sound signal power for a “desktop” speaker, an amplifier was integrated. The first device prototype was based on 5 V DC which is also used by the amplifier. However, this resulted in high current usage (more than 1 A) by the amplifier. Thus. in the current stage of development the amplifier supply voltage has been risen, which led to lower current requirement.

The audio amplifier (cf. Figure 7) takes standard “SPK OUT” signal from the motherboard as sound signal input. The input connector and all other parts of the amplifying circuit are separated with an 1:1 audio transformer, which provides insulation between amplifier, speakers and other parts of the device.

The core of the circuit is a 10 W, 12 V audio amplifier with a high current output. Power is provided by a classic voltage regulator with a wide input voltage range (15 V - 27 V). For this reason, the amplifier circuit is very resistant to supply voltage fluctuations.

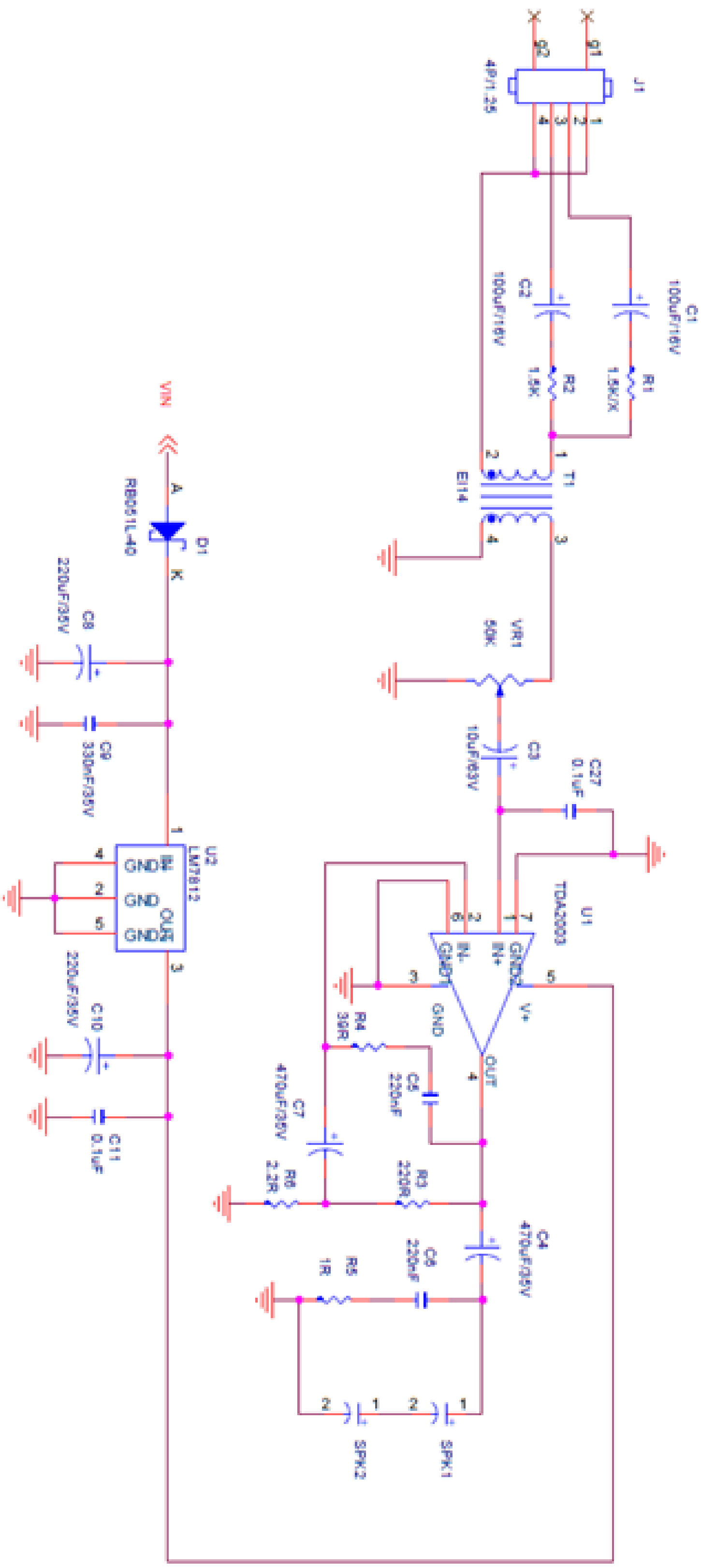

Figure 7: Circuit scheme of the audio amplifier circuit. For simplicity, a mono amplifier scheme is shown. The stereo system which is built into the KNOTS system requires two amplifiers, one for each loudspeaker.

4.3. Power Supply

Most of the components used require 5 V DC power supply. However, as already discussed before, lower voltage requires higher current which can lead to various problems. A part of the solution was a raise of audio amplifier supply voltage from 5 to 12 V DC. But parts of device still require 5 V (e.g. the motherboard), so an additional power supply circuit was required. A wide input voltage range step-down voltage regulator is used now for the KNOTS device, which also provides a very good resistance to input voltage fluctuations.

As the device now requires a higher voltage compared to the first prototype, battery-based supply also had to be adapted. A multi-cell battery is used, wired to a digital battery charging controller. Everything is powered by an external 230 V AC to 24 V DC rectifier. But, as already mentioned, the device itself has internal voltage regulation, quite resistant to voltage changes. So even a standard 19 V power supply (such as the ones used in laptops) can be used.