An Extendible Communication as a Service Platform for Wearables and Future-Oriented Devices

Roman Englert[1], Jörg Muschiol[2]

Abstract: Wearables are suitable devices for communication, navigation, and orientation, since they are easy to wear, and comfortable companions. A demerit is that most of them need to be connected to a master device or a server that provides the content. In this paper we propose and evaluate a prototype of a communication as a service (CaaS) platform that enables any wearable to be connected with. The architecture, and the implementation of the communication platform are described. Real probands were acquired for the evaluation of the CaaS system. The evaluation is based on communication tasks that were executed by the probands and are compared to the situation without the assistance of wearables and the communication platform in the background. A well-known usability measure, namely the Kullback-Leibler divergence is used to demonstrate the effectiveness of the CaaS platform that increases the usage of wearables for communication tasks by a factor of 2.58.

Keywords: Wearables, Communication as a Service (CaaS) Platform, Architecture, Usability, Evaluation

1 Introduction

Today communication is a ubiquitous appliance. This behavior emerged due to the invention of wireless devices like cellular phones (so-called mobiles) and cellular networks with fast data transmissions. The next generation of mobiles are wearables that are bracelets, smartwatches, glasses, etc. or communication devices that are integrated into clothes [Mu14]. Wearables have limitations, since they are small-sized, lightweight devices with small accumulators. Thus, they need a short-distance connection to a powerful smartphone. In the case they are offline, their internal storage can be used to collect and store data like geo-position, health condition, etc. Those data can later be transferred and processed in the cloud or a cloud-based system can offer multimodal communication with smart services as proposed in this paper.

Cloud-based services that offer (multimodal) communication are known as communication as a service (CaaS) [Sp11]. They may contain voice over IP communication, instant messaging, and video calls / conferencing. Multimodal communication enables different communication modalities like speech, tapping, gestures in parallel [EG06]. The proposed CaaS consists of three different domains for devices like

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[1] University of Siegen, Faculty III, Institute of New Media, and FOM (University of Applied Sciences for Economy and Management), Siegen/Essen, roman.englert@t-online.de

[2] FOM (University of Applied Sciences for Economy and Management), Essen, muschiol@fom.de

wearables, data transmission, and users [Mu13]. All domains are processed in the cloud and thus fit perfectly to wearables. The separation of the domains makes the CaaS system expandable to new requirements by technological developments of wearables.

The evaluation is done with a data set of 30 probands [Mu14]. The underlying scenario is a grandma going to an appointment with her doctor. She needs assistance to finding the way and to arrive in time due to physical, and mental weakens. Assistance is brought to her by wearables in form of communication and navigation services. The probands had to fulfill six communication tasks with smart devices and six without. The execution times were measured and compared for the tasks with, and without wearables. These measurements were also compared with the Gaussian distribution, assuming that the skills for using these smart devices are normal distributed. This comparison is done with the deviation measure Kullback-Leibler divergence (KLD) that is known from statistics [Ha69]. The KLD is insensitive to outliers, which is important for real data. The evaluation shows that the probands were able to reach their appointment with the assistance of the wearable-based services, and the execution times of the tasks were reduced by a factor of up to six. Additionally, the comparison with the KLD showed that the tasks execution improved with the usage of the wearables by a factor of 2.58.

The structure of the paper is as follows: wearables as communication devices are described in Sect. 2. Then, the proposed and implemented CaaS system and its architecture are described in Sect. 3. The evaluation with the real probands is done in Sect. 4, including a description of the scenario and how the measurements were taken. A brief introduction into the KLD is provided and the data evaluation is included. Sect. 5 contains the discussion of the results. The paper concludes with a summary and outlook for further research in Sect. 6.

2 Wearables as Communication Devices

Wearable Computing extends the usage of Information and Communication Technology (ICT) with small, body-worn, hands-free to use devices [De99]. Additionally, it enables new possibilities of mobile, context-sensitive technology usage with the extension of the human senses that can be enhanced by sensor integration in the devices [Ma13]. The devices can interact context aware autonomously or in addition to other devices, e.g. smartphones or embedded systems in cars. Mann [Ma98] describes three modes how wearable devices interact: 1) The constant mode provides a permanent and stable interaction with the user. 2) The augmentation mode offers interchange with the user, the device, and the environment without distraction of the real world. 3) Capsulation between human and the device is supported by the mediation mode which filters information in the solitude mode and provides security of the individual in privacy mode.

Many devices are named “wearables” (e.g., watches, wrists, bracelets, glasses, textiles and accessories) and the Human Computer Interaction (HCI) differs from device to device [Ra15], sometimes with poor approaches of user engagement. Wearables are used in scenarios where they support human communication activities in domains as health care, activity recognition, fitness, elder care, and entertainment.

Challenges of using wearables efficiently are often small displays, poor computing power, and small accumulator capacity. As a consequence, the user has to recharge them often (e.g. Samsung Gear S average charging period is about 2 days), with complicate and unmanageable procedures and s/he has to remember to wear the device. Many devices need additional steps or more equipment to be enabled and that results in low user involvement [Pa15]. In 2014 Motti and Caine [Mo14] evaluated success attributes for the user acceptance of wearables, e.g.:

- UX/UI & Usability (intuitive, simple and easy to use devices)
- Quality (audio, video and image resolution with high contrast, details and sharpness),
- Contextual awareness (external factors as light, brightness and noise),
- Battery lifetime (time to charge, compatible chargers),
- Price and overall costs (overall costs and benefits),

In a survey with wearable devices users, 75% described themselves as “early adopters of technology” and 48% were younger than 35 years, with an income of more than US $ 100,000 annually [Ni14]. Smartwatches are one of the first device categories of wearables which move from the specialist market to the mainstream. Recent advances in miniaturization and diminishing costs in processor, sensors, and communication technologies enable multisensor devices with capabilities to measure the heart-rate, galvanic skin response, activity level, and also supporting gesture or speech recognition [Ra15]. Most of them act as an additional display/device (e.g., Pebble, Apple Watch, Motorola Moto 360), and a minority also enable fully independent communication, and interaction with an autarkic voice and data connection (e.g. Samsung Gear S [Sa16]) with an own (e)sim card. The operating systems of, e.g., Samsung Tizen, Android Wear or Apple Watch differ in proprietary features, and usability concepts.

One demerit of smartwatches is the tiny display. The device needs to be small enough to be worn on a wrist and as a result the user interface is restricted by the size (especially for fashion- oriented watches). Supporting multimodality voice in- and output can help to solve this problem. As a wearable acts contextual, the application appears smart for the user interaction, and the combination of GSM, Wi-Fi, and GPS is mandatory. As a result of the combination of all sensor data, the CPU and sensor activity minimize the energy supply. Context awareness is still one of the most important research topics in wearable computing, challenged by the location awareness for indoor and outdoor scenarios [Ro14].

Wearable computing devices as “Google Glass” [Go16], “Oculus Rift” [Oc16], and “Microsoft HoloLens” [Mi16] belong to the category of Eyewear Computing with Head-Mounted Devices (HMD). They extend the real world with contextual digital information layered on the real environment (Google Glass) or they enable virtual reality platforms where the user walks with an avatar through a virtual environment, enhanced with real time gestures and objects. (Oculus Rift, Microsoft HoloLens). In 2014 Roggen [Ro14] stated that wearables as “Google Glass” should not replace the reality but they seamlessly augment it with micro interactions (only two to four seconds) and the technology has to stay out of the way when it is not needed [Ro14]. Kimura developed an eyeglass based videoconferencing system which fuses the images from four to six fish-eye cameras on the front glass frame to reconstruct the users face and send this to the video conference partner (see Fig. 1, a). Thus, media rich User Experience (UX) video conferencing becomes possible with just one sole wearable-only solution [Ro14].

Research topics as “Augmented Reality in a Contact Lens” [Pa09] demonstrate the future potential of Eyewear computing with the Augmented Reality (AR) technology. Googles project “Contact Lens” aims to assist people with diabetes by constantly measuring the glucose levels in their tears, and supports wearable healthcare scenarios [Fa15]. Hiroki Watanabe supports an approach of a miniaturized, integrated dietary monitoring with acceleration sensors integrated in a tooth (see Fig. 1, b) [Ro14].

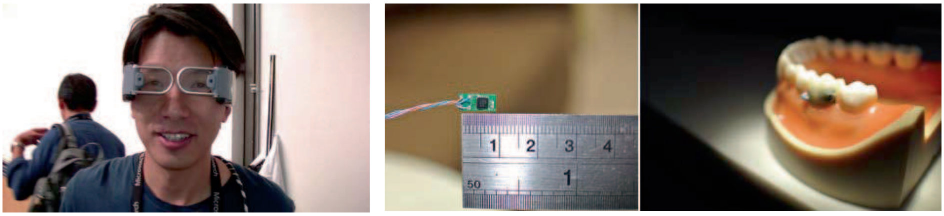


Fig. 1: (a) Eyeglass-based video conferencing system / (b) Dietary monitoring integrated in a tooth

Actually, a lot of research projects and also end-user products of pervasive wearable computing are upcoming. Giving some final examples:

The “dash” (see Fig. 2, a) earables are a new category of autarkic, seamless, wireless earphones, combined with high-level sensors. They support measuring health parameters combined with convenience wearing comfort, an aesthetic design and UX. The integrated microphones enable this device as a smart communication wearable [Br16]. Another innovative approach of a (text) communication device with a high level fashion design is the eyecatcher bracelet (see Fig. 2, b). This e-ink supported wearable is adaptive to the context, enables the communication via text and solves the problem of user acceptance by being a piece of jewelry. It is also nearly energy autarkic through the low energy consumption of the e-ink display [Lo16].

Fig. 2: (a) „Earable“ seamless, wireless smart earphone / (b) Eyecatcher fashion e-ink bracelet

Yokota et al. demonstrate an ultra-flexible, and conformable three-color, highly efficient polymer light-emitting diodes (PLEDs), and organic photodetectors (OPDs) to realize optoelectronic skins (oe-skins). That introduce multiple electronic functionalities such as sensing, and displays on the surface of human skin (see Fig. 3). The total thickness of the devices, including the substrate, and encapsulation layer, is only 3 µm, which is one order of magnitude thinner than the epidermal layer of human skin [Yo16]. This example depicts the next level of body worn technology.

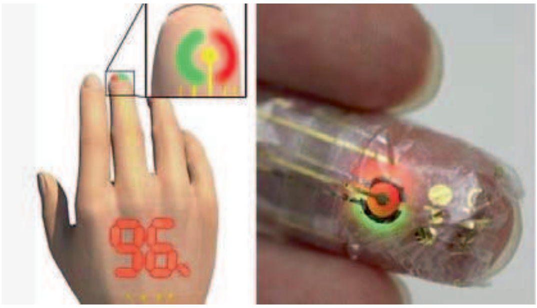


Fig. 3: Ultra-flexible, and conformable three-color display

Although wearable devices have the potential to facilitate communication, and information demands on a variety of application domains, this benefit might not be driven by one devices alone. The successful use, and potential benefits to an interaction of a mass of devices, and their combined interaction of communication.

In the following, an architecture platform including future technologies as expected for future communication will be described and discussed.

3 CaaS and the Architecture

The proposed CaaS system is based on an architecture with three domains [Mu13] (Fig. 4): The domain “anybody (left and right part) contains the user. S/he may communicate in a multimodal manner with speech, gestures, mimic and haptic according to individual preferences. Multimodal communication must be supported by the applied devices that are part of the domain “any device” (interior left and right side).

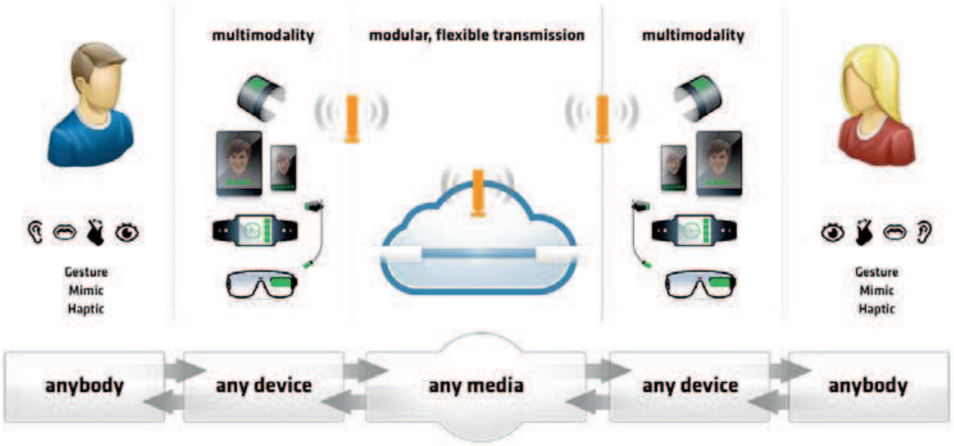


Fig. 4: Universal communication model (UCM) for wearable communication devices

If wearables are used, then it is recommended to connect them to a cellular phone (mobile) that contains a powerful accumulator. Finally, the domain “any media” consists of networks like LTE for the data transmission. These networks enable users to be nomadic and to transfer data with high quality and low latency.

The implementation of this architecture is done by several modules (Fig. 5) that are part of the universal communication platform (UCP): the left column contains the processing modules for the users’ input/output devices. These devices support media richness and multimodality. Here, media richness combines HD video and audio input/output, and provides the interaction application for data aggregation of external information sources like location or weather data. Touch devices enable sensor input that is processed by the application server (center column). Additional devices (bottom left part) are further displays or interaction devices like wearables, smartwatches and loudspeakers. They interact directly via a wireless connection with, e.g., a phablet to support multimodal interaction. The center column of the UCP contains a server running applications for data and client aggregation. Finally, the external services (right column) provide further information sources like NFC or video streams and from value-added content providers for e.g. weather information. Additional functionalities from external services like text-to-speech (TTS) for multimodality and WebRTC (We16) for integrated audio and video communication can also be processed.

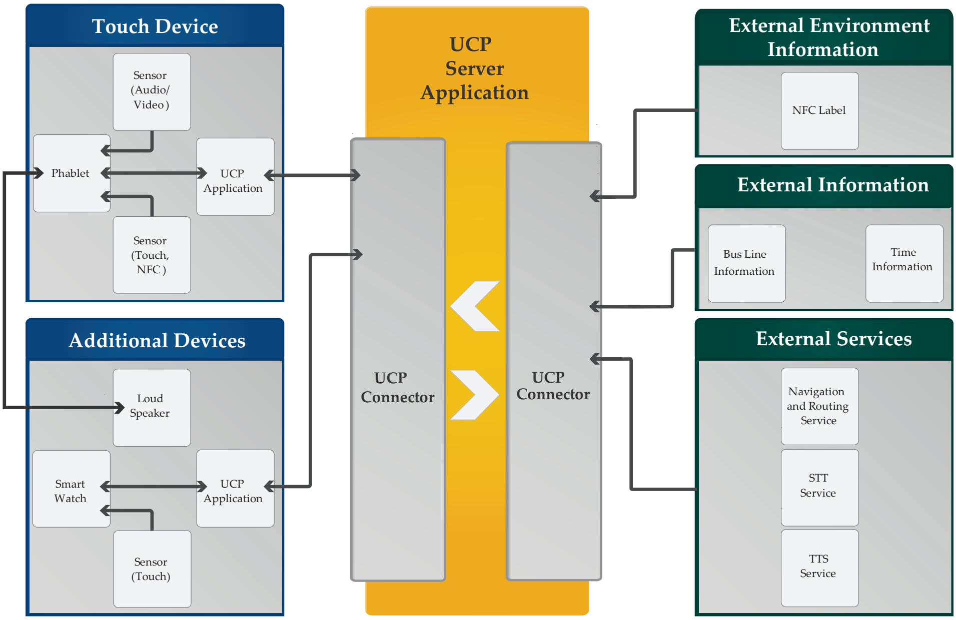


Fig. 5: Architecture of the UCP for wearables

CaaS offers multimodal communication for light devices like wearables, since computing intensive applications are executed in the cloud. The necessary high quality connection is provided by wireless networks like LTE and the wearables can be connected to LTE via a powerful smartphone. The implemented platform offers additional services for any user and any future device, especially wearables.

4 Evaluation: Tasks and Measurements

The evaluation is based on the scenario that a grandma with physical and mental capability loss has an appointment with her medical doctor and she needs to use the public transportation system and to walk the last mile in order to visit the clinic (Fig. 6). Grandma has a wearable equipment consisting of smartglasses, a bracelet with vibration, a phablet and a smartwatch. The smartglasses, the bracelet and the smartwatch are connected to the phablet that holds a LTE connection to the CaaS system which supports grandma on her way to the doctor.

Before grandma starts at home, the appointment is announced on her smartglasses and the bracelet is vibrating. She receives a TTS information for the navigation and starts to walk to the bus stop. After entering the bus, the phablet buys a ticket via NFC and the CaaS system acknowledges the appointment. The information to leave the bus is displayed on her smartglasses including the direction to walk. Secure street crossing is assisted by bracelet vibrations (warnings), when low contrast of traffic lights makes the separation of the colors red / green difficult. Her vital condition can be checked before she may decide to use the stairs in the clinic.

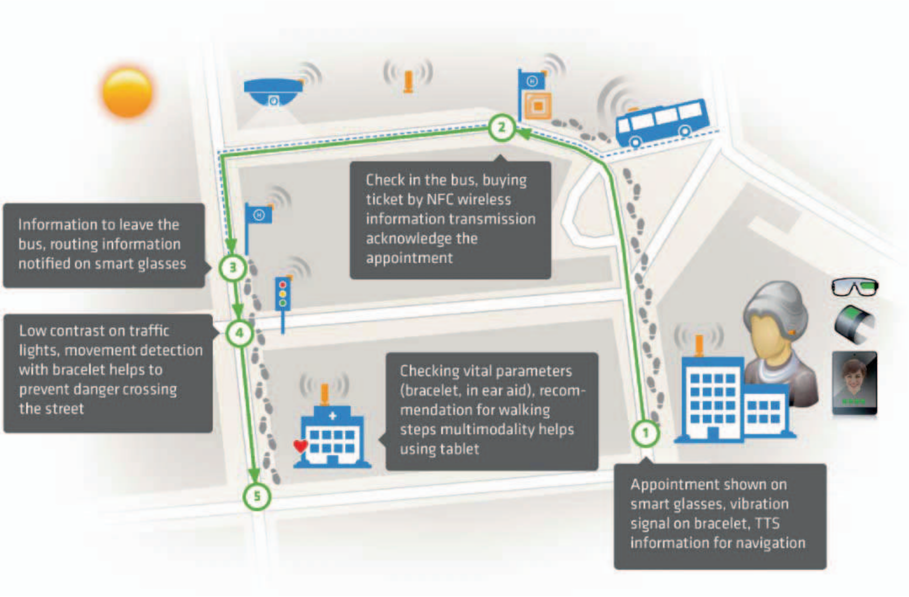


Fig. 6: Grandma’s way to the doctor and navigation support due to her physical limitations

This scenario is simulated in a laboratory with six stations, where the probands have to execute different tasks (Fig. 7) [Mu14]:

1. Plan the trip.
2. Select the proper bus line.
3. Determine the current position.
4. Navigate on a street crossing.
5. Check the time schedule during the trip.
6. Confirm the appointment.

The CaaS supports the probands by providing the above in the scenario described information and the user just has to confirm an action. In the case, where the CaaS is not available the probands have to use paper maps and bus plans, and a smartphone. The challenge for the probands is on one side to use the different wearables and the CaaS, and on the other side to interpret maps and bus plans, and to use the smartphone.

Fig. 7: A proband checks the time schedule during a trip and confirms appointment (tasks 5 and 6)

The 30 probands have been selected according to their ICT usage [Mu14]: more than half of them are using communication devices, digital photography, and a tom-tom. Only one third uses online banking, online shopping, electronic calculators and calendars. All probands are 60+ and many of them had a mental and/or physical capability loss which makes the usage of wearables a challenge, since they are unexperienced with them.

P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P21	P23	P24	P25	P26	P27	P28	P29	P30
114	49	89	153	77	82	86	69	138	71	63	80	89	75	94	45	79	31	29	94	94	46	70	126	90	86	106	93	57	121
91	99	106	65	27	28	70	39	69	25	36	40	28	26	82	47	44	26	31	86	85	20	34	51	90	48	95	44	39	95
32	41	39	5	27	4	14	6	61	22	21	11	28	15	30	10	29	21	14	8	10	5	11	6	17	6	11	20	15	38
12	34	21	14	2	8	17	24	6	85	2	12	7	12	15	17	13	5	15	2	5	3	9	7	8	8	8	10	4	6
65	70	41	32	10	44	33	27	21	15	38	27	63	8	76	19	41	10	14	11	52	24	51	38	27	16	11	28	21	58
40	32	30	30	40	24	27	19	33	26	29	31	18	18	34	24	31	21	16	18	33	22	21	39	25	20	55	27	29	44
62	23	46	29	21	25	11	11	19	29	21	21	25	5	9	7	10	12	9	25	40	22	9	11	18	12	51	9	20	19
37	19	32	13	57	5	10	28	52	19	17	16	21	18	16	16	32	5	5	5	69	29	16	22	44	24	16	13	48	24
19	29	34	27	15	20	14	31	28	34	14	13	20	31	24	16	18	14	15	17	48	14	21	14	21	18	42	22	17	54
12	17	19	13	14	9	11	9	8	9	10	10	9	14	8	13	11	13	7	13	9	8	10	7	7	8	7	7	6	9
10	15	15	11	8	8	8	8	13	10	16	8	10	14	14	9	12	18	6	6	8	10	7	8	7	1	5	6	6	10
4	3	10	12	4	3	5	2	8	4	3	3	3	5	5	3	3	2	1	2	4	3	1	2	6	2	3	1	1	3

Tab. 1: Six task execution measurements for the 30 probands without CaaS support (top) and six measurements with CaaS support (bottom)

Each proband had to perform six tasks without wearables and CaaS support and six tasks with wearables and CaaS support. The execution times were measured resulting in 30 x 6 x 2 = 360 measurements (Tab. 1). In the subsequent section these measurements are evaluated and discussed.

5 Results and Discussion

The evaluation of the measurements is done with two methods: First, the time measurements without and with support of wearables and the CaaS are compared with each other (Sect. 5.1). Second, the measurements are converted into statistical distributions to compute the deviation of the Gaussian (normal) distribution. The deviation provides a measure for the capability of the probands to use wearables, where the normal distribution is the bias (Sect. 5.2).

5.1 Comparison of the Time Measurements

The measurements for the execution of the six tasks without the usage of wearables and CaaS are the following (Tab. 1): Task 1 between 29 and 153 seconds 15(1st row). Task 2 between 20 and 106 seconds (2nd row). Task 3 between 4 and 61 (3rd row). Task 4 between 2 and 85 seconds (5th row). Task 5 between 8 and 76 seconds (5th row), and task 6 between 18 and 55 seconds (6th row).

The measurements for the six tasks with the usage of wearables and CaaS are the following (Tab. 1): Task 7 between 5 and 62 seconds (7th row). Task 8 between 5 and 69 seconds (8th row). Task 9 between 14 and 54 (9th row). Task 10 between 6 and 19 seconds (10th row). Task 11 between 1 and 15 seconds (11th row), and task 12 between 2 and 12 seconds (12th row).

The time intervals are compared by computing the improvement of the task executions in percentage for the minimum and the maximum of the intervals without and with wearables: Task 1 ((|5-29|)/29*100% = 83%, 60%), task 2 (75%, 35%), task 3 (71%, 13%), task 4 (67%, 347%), task 5 (700%, 407%), and task 6 (800%, 358%). Hence, the minimum execution time improvement is up to 800% and the maximum execution time improvement is up to 358%. The results show that especially the latter two tasks, namely 5 resp. 11 and 6 resp. 12, both are strongly supported by the wearables and CaaS. A limitation of this comparison is the outlier sensitivity. Therefore, an entropy-based measure is applied in the following section.

5.2 Comparison of the Time Distribution and the Gaussian Distribution

The Kullback-Leibler divergence (KLD) is an entropy-based measure in order to compute the divergence of two statistical distributions [CT91]:

$$\mathrm{D}(\mathrm{P}||\mathrm{Q}) = \Sigma_{\mathrm{x}\in\mathrm{X}}\mathrm{p}(\mathrm{x})\log\frac{\mathrm{p}(\mathrm{x})}{\mathrm{q}(\mathrm{x})}\ , \tag{1}$$

whereas $P(X)$ is the sample (measurement) and $Q(X)$ the theoretical sample distribution, with $\mathrm{p}(\mathrm{x})/\mathrm{q}(\mathrm{x}) > 0$. In the field of parametric tests sample distributions are compared with a theoretical distribution [Ha69]:

1. The unique distribution, where each data point occurs with the same probability:

$$U(x) = \left(\frac{1}{n}, \dots, \frac{1}{n}\right), \tag{2}$$

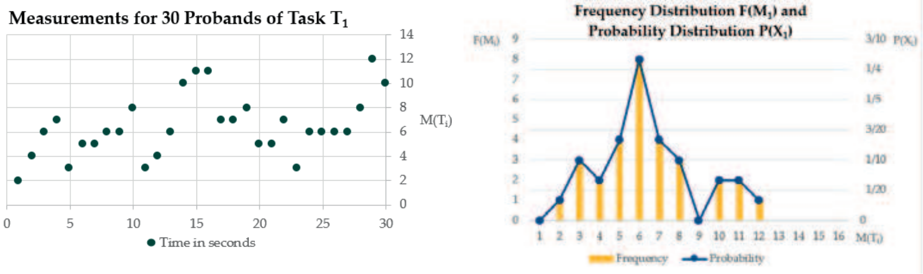
or a curved distribution like

2. The Gaussian distribution, where the assumption is, that the capabilities of the probands are normally distributed. However, the mean $\mu = \frac{1}{n}\Sigma x_i$ and the variance $\sigma^2 = \frac{1}{n}\Sigma(X_i - \mu)^2$ of X need to be computed:

$$G(x) = \left(\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x_1-\mu)^2}{2\sigma^2}}, \dots, \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{\left(x_n-\mu\right)^2}{2\sigma^2}}\right). \tag{3}$$

Summarizing, in the forehand evaluation compares the KLD (Formula (1)) the distribution of the measurement with the Gaussian distribution (Formula (3)). A larger entropy means, that there is more uncertainty for a distribution. The distribution of the measurement is achieved by computing the frequency distribution from the measurement, and subsequently converting the frequency distribution into a probability distribution [Ha69]. Fig. 8 shows an example for the measurements (left part) and the frequency and probability distributions (right part).

Fig. 8: Exemplary time measurements for 30 probands (left part) and the corresponding frequency (yellow) and probability (blue) distributions (right part)



In the case without the support of wearables and CaaS are the KLDs for the six tasks (Formula (1)): 3.154, 2.691, 1.611, 2.157, 2.157, and 1.932. Since the KLD is an entropy-based calculation, indicate smaller numbers a better fitting of the measured probability distribution with the Gaussian distribution. Thus, the 3rd task measurement has the best fitting of both distributions and the 1st task measurement a less good one with the Gaussian distribution. This means, that the execution times of the probands for the 3rd task are nearly normal-distributed, and in contrast to this have the execution times for the 1st task some outliers according to the Gaussian (normal) distribution.

The other case, where the support of wearables and CaaS is used for the task execution, shows the following KLD computations: 1.962, 2.174, 1.861, 1.036, 0.835, and 0.845. Smaller KLDs indicate lesser outliers for nearly all tasks compared without the usage of wearables, except task 3 "determine your current position" was easier without wearable support. Especially tasks 3-5 were much easier to solve with wearables and CaaS support.

In total the execution of the tasks with wearable and CaaS support has a better fitting of the measurements with the Gaussian distributions than the executions without wearable and CaaS support. This result underlines the usefulness of wearables combined with a CaaS system to solve communication tasks.

6 Summary and Outlook

In this paper we have shown that wearables are useful devices to fulfill communication and navigations tasks. This result has been proven for elderly people with physical or mental loss. Additionally, the chosen probands were digital immigrants, that were not used to wearables. It has been shown that the maximum execution time for the tasks could be improved up to 358%. For five of six tasks the elderly probands were nearly normal distributed with less outliers according to their capabilities to handle wearables. Furthermore, navigation support systems ("when to leave the bus", "next crossing right") are more reliable than the human memory.

A central key factor for using wearables are an easy connectivity and an easy interaction interface. Unfortunately, the manufacturers differ in their design and interaction paradigms. Additionally, they differ in their functionality, especially for multimodal communication. Therefore, we plan to develop a common user interface with a common functionality set for wearables that is also suited for outdoor application.

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