D3.4 Requirement analysis and sensor specifications (final version)

Editors: Puneet Sharma, Hui Xue, and Fridolin Wild
# Revision History

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Requirement analysis and sensor specifications- Final version

WP 3 | D3.4

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Executive summary

In this deliverable, we take into account the results from first set of trials associated with the first wave of the WEKIT prototype (from D3.2 and D3.3). Based on the results and discussions in a technical workshop at Heerlen (20 and 20 November 2017), we propose a final set of requirements and provide an overview of a set of sensors that can be used to meet the requirements and needs of this project. Based on the overview, we give a set of recommendations that can be used for the development and integration of the final version of the hardware and software platforms. The recommendations include a microcontroller and the associated state-of-the-art sensors, power supply, wiring and communication mode that can be used. These recommendations will be used by the later deliverables of the WP3 and WP5.
1. Introduction

In this report, first we outline a set of requirements for the second wave of the WEKIT prototype. Revisit the mapping table that maps the so-called transfer mechanisms to the associated sensors. Next, we discuss the reasons behind the need for a microcontroller, followed by a brief overview of a few state-of-the-art microcontrollers. After that, we discuss a set of sensors associated with a state-of-the-art microcontroller and its power supply & communication. Furthermore, we outline future extensions in terms of displays, physical buttons, UI and wiring that can be considered in WP5 at a later stage. Finally, in the discussion section, we provide a set of recommendations for the WEKIT hardware and software platform.
2. Method

In this section, we discuss the latest requirements for the second wave of WEKIT prototype. We also discuss the mapping of high-level tasks to the associated sensors. Next, we discuss a few state-of-the-art microcontrollers that can be used for the WEKIT system, followed by the sensors that can be coupled with it. Finally, we discuss the power supply and communication challenges and make recommendations.

2.1. Requirements

For the three use cases (mentioned in D6.1, D6.2, and D6.3), the first wave of the WEKIT prototype was evaluated and the results are discussed (in D6.4, D6.5, and D6.6). Based on the results, comments from the reviewers, and a meeting of technical partners on 20 and 21 November 2017, a final set of requirements were formulated for the second wave of the trials.

The requirements include:

- **RQ1**: We need processing power (for data processing, machine learning, analytics and, as per section 2.2, deducing how those processing activities can be combined [mapped] to inform the selection and instantiation of instructional methods [perhaps augmented with biofeedback and personalised to each user]) and for communicating the sensor data to the stick PC i.e., Sensor Processing Unit (SPU). In future for more advanced AR glasses, we can transmit the data directly to the AR glasses hence reducing or eliminating the need for SPU.
- **RQ2**: We need good battery life for sensor processing with cold swap possibility for the battery.
- **RQ3**: We need quick and reliable communication.
- **RQ4**: We need alternative offline use for SPU (with no live internet connection).
- **RQ5**: All sensors need to run on same voltage.
- **RQ6**: We need to use more open platforms and open hardware.
- **RQ7**: We need to focus on cheap hardware.
- **RQ8**: The proposed solution should be modular and extensible.

2.2. Mapping

The authors[1], define instructional methods as transfer mechanisms i.e., methods that facilitate the transfer of knowledge. RQ1-8 considerations are implicit in the Key Product column of Table 1 which shows examples of transfer mechanisms which, taken as a group, are not yet available in the marketplace but which will become core tools for the EU’s trainers, according to our user trials (TAM, technology acceptance model studies). Table 1 includes: remote symmetrical tele-assistance, virtual/tangible manipulation, haptic hints, virtual post its, mobile control, in situ real time feedback, case identification, directed focus, self-awareness of physical state, contextualisation, object enrichment, think aloud protocol, zoom, and slow motion. In this section, we decompose the different transfer mechanisms to low-level functions and their associated state-of-the-art sensors.

<table>
<thead>
<tr>
<th>Transfer mechanism</th>
<th>Description</th>
<th>Sensors</th>
<th>Key products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote symmetrical tele-assistance</td>
<td>View and capture the activity of another</td>
<td>smart/AR glasses</td>
<td>Moverio BT-200/2000, Microsoft HoloLens,</td>
</tr>
<tr>
<td>Transfer mechanism</td>
<td>Description</td>
<td>Sensors</td>
<td>Key products</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------</td>
<td>---------</td>
<td>--------------</td>
</tr>
<tr>
<td>person from their perspective transmit video &amp; audio.</td>
<td>Depth camera, smart armband</td>
<td>Sony SmartEyeglass, Google Glass, Meta 2, Vuzix M-100, Optinvent Ora-1, ODG R7</td>
<td></td>
</tr>
<tr>
<td>Virtual/ tangible manipulation</td>
<td>Hand movement tracker, accelerometer, and gyroscope.</td>
<td>Myo Gesture control armband, Leap Motion controller.</td>
<td></td>
</tr>
<tr>
<td>Haptic hints</td>
<td>Vibrations on arm or fingers</td>
<td>Vibrotactile bracelets and rings.</td>
<td>Myo, magic ring</td>
</tr>
<tr>
<td>Virtual post its, contextualisation, in situ real-time feedback</td>
<td>Object tracking in environment.</td>
<td>Smart glasses, Tablet Computer or Mobile Phone.</td>
<td>Several</td>
</tr>
<tr>
<td>Mobile control</td>
<td>Control dials and other user interface elements.</td>
<td>Hand gesture, controller.</td>
<td>Myo, Leap motion.</td>
</tr>
<tr>
<td>Case identification</td>
<td>Link with existing cases, link with error knowledge.</td>
<td>Case based reasoning component</td>
<td>No specific sensor</td>
</tr>
<tr>
<td>Directed focus</td>
<td>Direct focus of user</td>
<td>Gaze direction / object recognition, EEG (attention/focus/mental effort)</td>
<td>Smart Glasses (or gyroscope only), MyndPlay MyndBand, Interaxon Muse EEG, Neurosky Mindwave, Emotiv EEG.</td>
</tr>
<tr>
<td>Self-awareness of physical state</td>
<td>Fatigue level, vigilance level, Biodata (e.g., steps, sleep, heart rate, ), and body posture: ergonomics (e.g. lean back, forward).</td>
<td>EEG, smart watch, posture tracker.</td>
<td>MyndPlay MyndBand, Neurosky Mindwave, Emotiv EEG, Fitbit, apple watch, LeapMotion, Myo, Lumo Lyft, Alex posture.</td>
</tr>
<tr>
<td>Think aloud protocol</td>
<td>Capture voice of the user</td>
<td>Microphone</td>
<td>Cochlea Wireless Mini Microphone, built-in microphone of Camera/Smart Glasses, Wireless Microphones (e.g. from AKG).</td>
</tr>
<tr>
<td>Zoom</td>
<td>Zoom in and get details</td>
<td>Smart glasses / tablet with high-resolution camera</td>
<td>Several</td>
</tr>
<tr>
<td>Slow motion</td>
<td>Allow replay at slower speed</td>
<td>High frame rate camera (high frame rate often comes at price of resolution with smart glasses; and vice versa),</td>
<td>Several</td>
</tr>
</tbody>
</table>
The mapping from transfer mechanisms to sensors is not injective. For instance, a transfer function such as remote symmetrical tele-assistance requires both audio and video information, for which we need more than one sensor. On the other hand, some smart glasses (such as Microsoft HoloLens) are equipped with a number of integrated sensors, which enables it to capture various transfer mechanisms. As an example, Microsoft HoloLens [2] consists of the following sensors:

- 1 IMU
- 4 environment understanding cameras
- 1 depth camera
- 1 2MP photo / HD video camera
- Mixed reality capture
- 4 microphones
- 1 ambient light sensor

Some transfer mechanisms (e.g., virtual post its, contextualisation, in situ real-time feedback) need highly processed information provided by subroutines or software libraries of an API. Some transfer mechanisms (such as zoom and slow motion) are computationally expensive and can be impractical based on the current state-of-the-art of wearable devices.

As shown in Table 2, we present an overview of the different transfer mechanisms along with the sensors under consideration. We can see that Microsoft HoloLens and built in sensors can support transfer mechanisms such as remote symmetrical tele-assistance, virtual post its, contextualisation, in situ real-time feedback, directed focus, think aloud protocol, and zoom. The Myo arm band supports transfer mechanisms such as virtual/tangible manipulation and mobile control. For case identification, no specific sensor is considered at the moment. For slow motion, we would need a high frame rate camera which would increase the cost of the prototype and reduce the wearability, hence, it is not considered in this wave of sensor selection. For self-awareness of physical state, we will need metrics such as heart rate variability and posture information. For haptic hints, we can use two vibration motors placed on the arms of the user. Since Microsoft HoloLens and Myo were selected in the first wave of the sensor selection process, in this sensor selection process, we will focus on the transfer mechanisms: self-awareness of physical state and haptic hints, which are linked with sensors such as galvanic skin response (GSR), heart rate variability, posture and vibration motor.

<table>
<thead>
<tr>
<th>Transfer mechanisms</th>
<th>Sensors under consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote symmetrical tele-assistance</td>
<td>Microsoft HoloLens and built in sensors</td>
</tr>
<tr>
<td>Virtual/ tangible manipulation</td>
<td>Myo</td>
</tr>
<tr>
<td>Haptic hints</td>
<td>Vibration motor</td>
</tr>
<tr>
<td>Virtual post its, contextualisation, in situ real-time feedback</td>
<td>Microsoft HoloLens and built in sensors</td>
</tr>
<tr>
<td>Mobile control</td>
<td>Myo</td>
</tr>
<tr>
<td>Case identification</td>
<td>No specific sensor</td>
</tr>
<tr>
<td>Directed focus</td>
<td>Microsoft HoloLens and built in sensors</td>
</tr>
<tr>
<td>Self-awareness of physical state</td>
<td>galvanic skin response (GSR), Heart rate variability and posture</td>
</tr>
<tr>
<td>Think aloud protocol</td>
<td>Microsoft HoloLens and built in sensors</td>
</tr>
<tr>
<td>Zoom</td>
<td>Microsoft HoloLens and built in sensors</td>
</tr>
<tr>
<td>Slow motion</td>
<td>High frame rate camera</td>
</tr>
</tbody>
</table>
2.3. Microcontrollers

During the first wave of trials in April to May 2017, it was observed that the communication of Microsoft HoloLens with EEG was problematic and its use was discontinued for the rest of the trials (D6.4, D6.5, D6.6). A later investigation revealed that the EEG was affected by environmental noise in the use case at Lufttransport where the moving parts of an aircraft generate a significant amount of electrical noise.

In addition to a Sensor Processing Unit (in the form of a stick PC) which collects and stores all the data, there is still a strong need to use sensors for analytics data such as heart rate variability, skin conductivity, and posture. To this end, we can make use of existing open source and open hardware platforms and the associated sensors supported by them.

As per the requirements outlined in Section 2.1, the platform should be compact in size, should be energy efficient while also being computationally powerful enough to handle data from different connected sensors. Furthermore, it should support a range of different sensors.

Among the open platforms, we looked at a selected list of open platforms, which support a wide range of sensors. This list includes Arduino ESP32, Lilypad, Raspberry Pi Zero, and BeagleBone Black. A brief summary of their comparison is provided in Table 3.

Arduino Lilypad [3] is optimised for sewing, which means that it can be integrated into the WEKIT wearable solution, however, it has limited number of input/outputs for connecting sensors and using Wi-Fi and Bluetooth as compared to the alternatives.

Raspberry Pi Zero [4] with support for a number of additional sensors is quite interesting as a potential candidate. In fact, a faster version of Raspberry Pi Zero can perform a role similar to that of Sensor Processing Unit / Stick PC in the near future.

BeagleBone Black [5] has a lot of features and support for sensors, however, it is bulky as compared at all others (in this report), does not fit our requirements and is also more expensive.

ESP32 is a low cost, low power system on a chip microcontroller with integrated Wi-Fi and Bluetooth [6]. It uses a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations and includes power amplifier, low-noise receive amplifier, filters, and power management modules [6]. ESP32 is created and developed by Espressif Systems and is a successor to the ESP8266 microcontroller [6].

Arduino is an open source computer hardware and software company, project, and user community that designs and manufactures single-board microcontrollers and provides an integrated development environment for a variety of microprocessors and controllers [7]. The microcontrollers are usually programmed using a dialect of features from the programming languages C and C++ [7]. **The Arduino IDE can be used to program ESP32.**

ESP32 (with additional display) comprises of a sufficiently fast platform with a number of inputs and outputs. It supports a number of wearable sensors (details in Section 2.4) that can be added in a modular fashion. It is low cost, supports open hardware and software development, is reliable and fulfils all our requirements. Based on the above-mentioned reasons, we would recommend ESP32 as a candidate for the sensor platform.
<table>
<thead>
<tr>
<th>Processor</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP32 with display [8]</td>
<td>▪ Small</td>
<td>▪ Running at 240 MHz dual core</td>
</tr>
<tr>
<td></td>
<td>▪ Cheap (6 to 13 Euros)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Has a display (can display messages from SPU/stick PC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Both analog and digital inputs/outputs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Wi-Fi and Bluetooth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ 2.3V to 3.6V operating voltage</td>
<td></td>
</tr>
<tr>
<td>ESP32 [9]</td>
<td>▪ Small</td>
<td>▪ Running at 240 MHz dual core</td>
</tr>
<tr>
<td></td>
<td>▪ Cheap (6 to 13 Euros)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Both analog and digital inputs/outputs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Wi-Fi and Bluetooth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ 2.3V to 3.6V operating voltage</td>
<td></td>
</tr>
<tr>
<td>ESP32 with battery [8]</td>
<td>▪ Same as above</td>
<td>▪ Same as above.</td>
</tr>
<tr>
<td></td>
<td>▪ Battery</td>
<td>▪ Battery lasts only 17h</td>
</tr>
<tr>
<td>LilyPad [3]</td>
<td>▪ Optimised for sewing in.</td>
<td>▪ Fewer inputs/outputs</td>
</tr>
<tr>
<td></td>
<td>▪ Cheap (18 Euros).</td>
<td>▪ No Wi-Fi, no Bluetooth</td>
</tr>
<tr>
<td></td>
<td>▪ Voltage: 2.7 to 5.5 V</td>
<td>▪ Needs to be USB connected to stick PC</td>
</tr>
<tr>
<td></td>
<td>▪ No. of digital I/O pins: 14</td>
<td>▪ 328 version has 20 MHz (8 MHz)</td>
</tr>
<tr>
<td></td>
<td>▪ No. of analog input channels: 6</td>
<td></td>
</tr>
<tr>
<td>Raspberry Pi Zero [4]</td>
<td>▪ Minimally bigger</td>
<td>▪ Not optimised for sensor processing,</td>
</tr>
<tr>
<td></td>
<td>▪ Cheaper (5 Euros)</td>
<td>▪ Should be used in addition - as alternative for Stick PC</td>
</tr>
<tr>
<td></td>
<td>▪ Via mini HDMI port can be connected to display</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ 1GHz single core CPU</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Micro USB power (5 V)</td>
<td></td>
</tr>
</tbody>
</table>
### Processor Advantages Disadvantages

<table>
<thead>
<tr>
<th>Processor</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeagleBone Black</td>
<td>- Alternative to SPU / Stick PC</td>
<td>- More bulky</td>
</tr>
<tr>
<td></td>
<td>- 1 GHz</td>
<td>- Expensive (46 Euros)</td>
</tr>
<tr>
<td></td>
<td>- 4 USB ports</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Ethernet.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Micro HDMI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- 3D graphics accelerator</td>
<td></td>
</tr>
</tbody>
</table>

**Please note** that we have to be careful with how many sensors we connect with a single ESP32. If the ESP32 is overloaded or inputs collide, we could lose data. It should be fine with the number of sensors we are planning for, but there may be a need to add additional ESP32 units in case we add more sensors. This could potentially be remediated with a data shield or buffer.

## 2.4. Sensors

In this section, we discuss the different state-of-the-art sensors associated with ESP32 or similar microcontrollers that can be used for analytics.

Heart rate sensor consists of three components: 3 biomedical sensor pads that are placed on different regions on the body, a sensor cable that collects the data from different sensor pads, a AD8232 chip which filters the noisy signal data associated with PR and QT intervals of ECG and gives an analog reading as an output [10]. This solution is intrusive and would be difficult to include in a wearable prototype.

Grove - Ear-clip Heart Rate Sensor [11], which uses an ear clip, is a better alternative from a wearability perspective. It is placed on the ear lobes. Its placement is relatively easy and subject can perform physical tasks while being monitored. The drawback is that it might not be possible to obtain consistent readings and accurate results due to noise generated owing to inadvertent head movements [12].

LilyPad Vibe Board is a buzzer [13]. It is a vibration motor that works as a physical indicator without notifying anyone but the one who is wearing it. It is small but powerful. However, it applies 5V and only works with LilyPad platform.

There are two types of vibration motors that can be considered. One is a shaftless vibratory motor. It looks like a coin but smaller than the size of a quarter. Its operating range is from 2 V to 3.6 V [14]. It comes with a 3M adhesive backing and reinforced connection wires. The other one is DC3V 0834 Mobile phone micro flat vibration motor. The diameter of the motor is 8 mm and the thickness is 3.4 mm. It applies the voltage range from 1.5 V to 3.7 V [15]. We need two vibration motors one on each arm to provide haptic feedback.

Grove - GSR Sensor is suggested for galvanic skin response (GSR). The electrical conductance of the skin can be detected and measured by electrodes. The electrodes are attached with finger cots. Grove
Wearable Experience for Knowledge Intensive Training

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Dissemination: Public
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- GSR Sensor has two electrodes attaching to two fingers on one hand. The input voltage of the Grove GSR Sensor is 5V/3.3V and the sensitivity can be adjusted by potentiometer [16]. The data from the GSR sensor will be used to estimate the stress/fatigue levels of the user, i.e. self-awareness of physical state of the user. This type of sensor is not optimal from a wearability perspective as it requires physical contact with the fingers on the hand, the associated wires make it difficult to use the hand for other tasks.

For measuring and reporting a body’s position, the inertial measurement unit (IMU) is needed. Two IMUs can be placed on the back of the user which then combined with the position of head (from HoloLens) can give us a good estimate on the posture of the user. This setup requires initial testing to determine the exact locations for the optimal placement of sensors and should be considered from both the ergonomics perspective (in WP5) and hardware development perspective (in WP3). SparkFun Triple Axis Accelerometer and Gyro Breakout - MPU-6050 is one of the choice. It is combined by a MEMS 3-axis gyroscope and a 3-axis accelerometer on the same silicon wafer. In addition to a Digital Motion Processor™ (DMP™) onboard, it is capable of handling complex 9-axis Motion Fusion algorithms. Therefore, the MPU-6050 eliminates cross-axis alignment problems that may creep on discrete components. The breakout board for the MPU-6050 is easy to work with in our project [17]. Another choice is SPI /IIC GY-9250 MPU 9250. It uses Standard IIC/SPI communication protocol [18]. This sensor combines with 9-Axis attitude, gyroscope, accelerometer and magnetometer. Supply Voltage is from 3 V to 5 V.

In this project, environmental temperature and humidity sensor are also considered. Environmental temperature and humidity data gives us a better estimate of feel like conditions. For this purpose, Humidity and Temperature Sensor SHT15 [19] and SHT1x [20] are suggested. Both of them are a single chip relative humidity and temperature multi sensor module comprising a calibrated digital output and they are from Sensirion’s family. The CMOSens® technology was applied for the sensors and provides excellent reliability and long-term stability [21]. Table 4 summarizes the details ofthe discussed sensors.

Table 4. State of the art sensor for Arduino platform. The sensors marked with (*) can be selected from different vendors

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Product</th>
<th>Specifications</th>
</tr>
</thead>
</table>
| Heart rate sensor (Single Lead) | SparkFun Single Lead Heart Rate Monitor - AD8232[10]                   | - Operating Voltage - 3.3V  
- Analog Output  
- Leads-Off Detection  
- Shutdown Pin  
- LED Indicator  
- 3.5mm Jack for Biomedical Pad Connection  
- Probe length 24“  
- Sensor pad dimensions 24mm x 1mm |
<p>| Sensor Cable - Electrode Pads (3 connectors) [22] |                                                                         |                                                                                |</p>
<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Product</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate sensor (Ear clip)</td>
<td>Grove - Ear-clip Heart Rate Sensor [11]</td>
<td>- Contains an ear clip for measuring heart rate and a receiver module&lt;br&gt;- Low power consumption&lt;br&gt;- Wide power supply range: DC 3~5V&lt;br&gt;- Convenient to use High sensitivity</td>
</tr>
<tr>
<td>Vibration Motor*</td>
<td>DC3V 0834 Mobile phone micro flat vibration motor [15]</td>
<td>- 1.5V-3.7V DC&lt;br&gt;- 12000-2500RPM Min&lt;br&gt;- 3.4mm height, 8mm width&lt;br&gt;- Rated current: 70 mA maximum</td>
</tr>
<tr>
<td>Galvanic Skin Response</td>
<td>Grove - GSR Sensor [16]</td>
<td>- Input Voltage: 5V/3.3V&lt;br&gt;- Sensitivity adjustable via a potentiometer&lt;br&gt;- External measuring finger cots&lt;br&gt;- Measures GSR at fingers&lt;br&gt;- Since the sensor velcro pads interfere</td>
</tr>
<tr>
<td>Sensor type</td>
<td>Product</td>
<td>Specifications</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IMU*</td>
<td>SparkFun Triple Axis Accelerometer and Gyro Breakout - MPU-6050 [17]</td>
<td>with normal hand use, this sensor is currently only experimental and likely not to be part of the operational kit. Still, it will allow exploring whether GSR data can be read in the environmental context we face with high enough reliability.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>IMU</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I2C Digital-output of 6 or 9-axis MotionFusion data in rotation matrix, quaternion, Euler Angle, or raw data format</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Input Voltage: 2.3 - 3.4V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Embedded algorithms for runtime bias and compass calibration. No user intervention required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Tri-Axis angular rate sensor (gyro) with a sensitivity up to 131 LSBs/dps and a full-scale range of ±250, ±500, ±1000, and ±2000 dps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Placed on the back, so we can sense posture.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ 3.5mA operating current when all 9 motion sensing axes and the Digital Motion Processor are enabled</td>
</tr>
<tr>
<td>Sensor type</td>
<td>Product</td>
<td>Specifications</td>
</tr>
<tr>
<td>-------------</td>
<td>---------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| IMU*        | SPI /IIC GY-9250 MPU 9250 [18] | ▪ Power supply: 3-5V (internal low dropout regulator)  
▪ Communication: Standard IIC/SPI communication protocol  
▪ Gyro range: ± 250/500/1000/2000 °/s  
▪ Acceleration range: ± 2 ± 4 ± 8 ± 16g  
▪ 3.5mA operating current when all 9 motion sensing axes and the Digital Motion Processor are enabled |
▪ Precise dewpoint calculation possible  
▪ Measurement range: 0-100% RH  
▪ Absolute RH accuracy: +/- 2% RH (10-90% RH)  
▪ Temp. accuracy: +/- 0.3°C at 25°C |
| Environmental temperature and humidity sensor (with breakout board)* | Temperature and Humidity sensor - SHT1x [20] | ▪ Supply Voltage: 3.5 - 5V  
▪ Low power consumption 30mW  
▪ Defined humidity: 0% .. 100% RH  
▪ Absolute humidity measurement accuracy +/- 2% RH (relative humidity 10-90%)  
▪ Sampling rate: ≤ 1 Hz |

2.5. Power supply

The proposed power supply plan as shown in Figure 1 comprises of using a power source such as power bank or battery that supplies power to both the stick PC and ESP32 microcontroller. The microcontroller uses part of its power on the connected sensors such as heart rate monitor, IMUs, and vibration motor.
In the WEKIT prototype, HoloLens has its own battery. The ESP32 microcontroller (platform and sensors) and stick PC need extra power supply. The microcontroller can be supplied with power in two ways. One way is to connect the power bank using a USB cable (usually there is a USB jack on the Arduino ESP32 or other similar platforms). The other way is to connect a Lithium Ion Battery (see Figure 2) via the JST jack, as shown in Figure 3. The JST connection supplies voltage within a range of 3.3 V, which is suitable for ESP32 [24].
Both the microcontroller and stick PC can be connected via USB to a single power bank. The commercially available power banks (for mobile devices) can be used as long as the power drawn is within the range. For example, one of the option is Xiaomi 16000mAh Power Bank (see Figure 4) which comes with two USB charging ports.

ESP32 has only one USB jack, therefore, a USB cable splitter is needed such that it can connect to both the power bank and the SPU i.e., stick PC. Figure 5 shows one such splitter cable. Figure 5 (a) is the cable with USB jack and Figure 5(b) is the cable with Micro USB jack. In one such setting, as shown in Figure 7 the USB male connector will be connect to the ESP32 unit and the split cables on the other ends can carry power on one and data on the other cable. The power end of the split cable can be connected to the power bank and the data end of the split cable can be connected to the stick PC. This way power can be distributed from the power bank to both the stick PC and the ESP32, while at the same time data can be transferred from the ESP32 unit to the stick PC via the same USB connection. **Please note** that it is possible that the stick PC might need extra power via another USB connection. Hence, a **power bank with two USB charging ports** is **recommended**. Furthermore, we will need a few USB adapters to connect different types of USB connectors (e.g., micro, mini, A, B) and male/female types among SPU, power bank and ESP32 (see Figure 6). It is important to note that **this setup should be thoroughly tested before implementation**.
Figure 5. (a) USB 2.0 Male To Dual USB Female Jack Splitter Cable [28]  
(b) Micro USB Male to Micro USB Dual Y Adapter Splitter Cable [29]

Figure 6. Different USB converters and adapters [30]

Figure 7. Proposed schematic for the communication using USB male to two port splitter cable
It is necessary to estimate the power consuming when choosing the power bank. This can be calculated as follow:

The maximum drive current for ESP32 i.e., the current that can be drawn by the sensors connected to ESP32 varies a bit depending on the model and if Wi-Fi and Bluetooth communication modes are enabled. As an example, ESP32 Thing can reliably supply up to 600 mA [31] and the pins labelled 3V3 are used to supply external sensors. This means that for a smooth operation, no sensors connected to ESP32 can exceed 600 mA limits. Based on the current requirements shown in Table 5, it can be observed that the selected sensors require a total of 159.5 mA of current to be drawn from the ESP32 microcontroller which is well within the maximum limits. During active transmission ESP32 Thing consumes nearly 150 mA even during Wi-Fi transmission [32]. This means that the total current consumption for the complete setup including ESP32 and the associated sensors can be approx. 309.5 mA, summarized in Table 5. Please note that the current drawn by ESP32 with display can be more which means that total current consumption will be more than the estimates obtained with using ESP32 thing. We need lab testing to make sure that the different components do not exceed the maximum current limits of ESP32 with display.

Table 5. Different sensors along with their current requirements

<table>
<thead>
<tr>
<th>Components</th>
<th>Quantity of the components</th>
<th>Current drawn</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP32 Microcontroller</td>
<td>1</td>
<td>150 mA (approx.)</td>
</tr>
<tr>
<td>Heart rate sensor (Ear clip)</td>
<td>1</td>
<td>6.5 mA (approx.)</td>
</tr>
<tr>
<td>DC3V 0834 Vibration motor</td>
<td>2</td>
<td>140 mA (approx.)</td>
</tr>
<tr>
<td>SPI /IIC GY-9250 MPU 9250 IMU</td>
<td>2</td>
<td>7 mA (approx.)</td>
</tr>
<tr>
<td>Temperature and Humidity sensor - SHT1x</td>
<td>1</td>
<td>6 mA (approx.)</td>
</tr>
<tr>
<td>Sum total:</td>
<td></td>
<td>309.5 mA (approx.)</td>
</tr>
</tbody>
</table>

### 2.6. Sensor Processing Unit

A stick PC is a device which has independent CPU or processing chips and which does not rely on another computer. In the prototype, the stick PC functions as a Sensor Processing Unit (SPU). Among all the stick PCs in the market, Intel® Compute Stick is chosen for WEKIT project since it is an Intel® x86-based Stick PC (see Figure 8). One of the latest version of Intel® Compute Stick is with pre-installed Windows 10 Home x86 and a quad-core Intel® Atom™ processor that makes many applications available to be used [33].

![Figure 8. Intel® Stick PC [34]](image-url)
For the connectivity of the Intel® Compute Stick, it uses the built-in antennas and Intel wireless technology for connecting and accessing files in the cloud. The built-in Bluetooth can be used for connecting wireless peripherals or transfer files from smartphone to the stick PC’s on-board storage. Furthermore, there are USB ports can connect the devices such as keyboard, mouse or Ethernet adapter [35].

For the power supply of the Intel® Compute Stick, a Micro-USB charging cable and power brick are used [36].

2.7. Communication

For communication of data between ESP32 and Stick PC i.e., SPU, we have three possibilities: Bluetooth, Wi-Fi, and wired or cable.

It is possible to communicate data from ESP32 to Stick PC via Bluetooth as ESP32 has support for Bluetooth. There would be the possibility to expose Bluetooth profiles, so that sensors can be interchanged easily. Bluetooth profiles for specific sensor types are listed at [37]. It seems, however, since we integrate multiple sensors on the same microprocessor board that we pipe out the data in one connection, thus, preventing the use of specific Bluetooth profiles. Otherwise, we would have to expose multiple Bluetooth connections - one per sensor. Owing to these issues, Bluetooth communication is not recommended.

HoloLens to Stick PC communication can run over Wi-Fi, requiring a local Wi-Fi to be exposed from the Stick PC or a working Wi-Fi connection in place. This could be a problem for use case locations that do not have a Wi-Fi owing to various reasons such as security and remoteness. For this case, also it means that Wi-Fi communication between ESP32 and Stick PC is not recommended.

We recommend sending the data collected from the ESP32 microcontroller and associated sensors via USB to the stick PC due to its reliability, robustness to environmental noise and electrical interference, and the fact that the Wi-Fi connection of the stick PC can be used for other purposes. Furthermore, this also enables the WEKIT prototype to run and gather data in an offline setting.
3. Possible Extensions

There are several extensions possible, which we list here. These are inputs to the WP5 user-centred design workshop promoting the ergonomic and aesthetic assembly into a garment.

We will provide an update on this in D3.5 (M27). The integration of the sensor hardware framework into the final wearable solution will be documented in D5.8 (M30). This latter document then will include an update on which of these possible extensions made it into the final wearable garment.

3.1. Displays

Activities in WP5 (and possibly WP4) will decide whether there is need for a display output (or a touch display for user input). We list here a couple of alternatives if such display would be needed. From the sensor capturing side, the minidisplay already on the ESP32 would be sufficient to display status information on whether sensors are connected or enough space for capturing is still available or any other status message. Table 6 lists some displays for possible considerations in WP5.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SparkFun Serial Enabled 16x2 LCD [38]</td>
<td>• 3.3V Serial LCD</td>
</tr>
<tr>
<td></td>
<td>• Incoming buffer stores up to 80 characters</td>
</tr>
<tr>
<td></td>
<td>• Backlight transistor can handle up to 1A</td>
</tr>
<tr>
<td></td>
<td>• Pulse width modulation of backlight allows direct control of backlight brightness and current consumption</td>
</tr>
<tr>
<td></td>
<td>• All surface mount design allows a backpack that is half the size of the original</td>
</tr>
<tr>
<td></td>
<td>• Faster boot-up time</td>
</tr>
<tr>
<td></td>
<td>• Boot-up display can be turned on/off via firmware</td>
</tr>
<tr>
<td></td>
<td>• 1.425 x 3.15” - 1” Thick</td>
</tr>
<tr>
<td>Adafruit Sharp Memory Display Breakout - 1.3” 168 x 144 Monochrome [39]</td>
<td>• Display dimensions (viewable): 24.5mm × 21mm</td>
</tr>
<tr>
<td></td>
<td>• Dot pitch: 34mm × 33.3mm / 1.34” × 1.31”</td>
</tr>
<tr>
<td></td>
<td>• Display size: 36.6mm / 1.44” diagonal</td>
</tr>
<tr>
<td></td>
<td>• Current draw depends on refresh rate: with 1Hz data refresh, its 12uW (4uA @ 3.3V)</td>
</tr>
<tr>
<td></td>
<td>• PCB Dimensions: 40mm x 39mm x 4.6mm / 1.58” x 1.54” x 0.18”</td>
</tr>
<tr>
<td></td>
<td>• Weight: 6g</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| Monochrome 1.3” 128x64 OLED graphic display [40] | - PCB: 35mm x 35mm x 5mm / 1.4” x 1.4” x 0.2”
- Screen: 23mm x 35mm / 0.9” x 1.4”
- Weight: 8.5g
- Diagonal Screen Size: 1.30”
- Number of Pixels: 128 × 64
- Color Depth: Monochrome (White)
- Module Size (mm): 34.50 x 35.00
- Panel Size (mm): 34.50 x 23.00 x 1.45
- 3.3V power supply and 3.3V logic levels for communication. |
| Adafruit 1.44" Color TFT LCD Display with Micro SD Card breakout - ST7735R [41] | - 1.44” diagonal LCD TFT display
- 128x128 resolution, 18-bit (262,144) color
- 4 or 5 wire SPI digital interface
- Use with 3.3V or 5V logic
- Onboard 3.3V @ 150mA LDO regulator
- 4 x 0.9”/2mm mounting holes in corners
- Overall dimensions: 33mm x 45mm x 7mm / 1.3” x 1.8” x 0.3”
- Weight: 10.6g |
| TFT FeatherWing - 2.4" 320x240 Touchscreen For All Feathers [42] | - Product Dimensions: 65.0mm x 53.0mm x 9.5mm / 2.6” x 2.1” x 0.4”
- Product Weight: 32.2g
- 2.4” Resistive touchscreen
- 240x320 pixels with individual 16-bit colour pixel control |
### 3.2. Buttons

Very basic functions: alternative for clicker / on-off switch for sensor framework. Table 7 gives the suggestion of buttons.

**Table 7. Buttons**

<table>
<thead>
<tr>
<th>Type</th>
<th>Product / Vendor</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button [43]</td>
<td>LilyPad Button Board Module</td>
<td>▪ Can be sewn with other materials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Cheap</td>
</tr>
<tr>
<td>Button [44]</td>
<td>WAVGAT Big button module Light touch switch module with hat High level output for Arduino</td>
<td>▪ colour coded (pack of 5 all with different colour)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ not easy to sew</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Cheap</td>
</tr>
</tbody>
</table>

### 3.3. UI and Wiring: Conductive Threads and Fabrics

Stoppa and Chiolerio [45] list conductive fibres (conductive fibre twisted with normal fibres), treated conductive fibres, conductive fabrics (using twisted metal wire, metal coating, or metal multifilament fibres), embroidery stitching patterns using conductive threads on regular fabrics, and conductive inks. They also review textile-based sensors successfully used, for example, for facial EMG. Conductive threads can be heavy, but good solutions are available on the market. They can be more brittle. Treated coatings preserve the characteristics of the yarns. Both can be utilised in embroidery, allowing for machine-supported production. Similarly, conductive inks allow for printing (which, however, is particularly sensitive to creasing, depending on viscosity of the ink).

Embroidery is the recommended technique to enhance the wearable hardware with buttons and, where needed, wiring -- using either twisted or treated conductive thread. Ready-made fabrics offer no direct advantage for circuit board layout, unless it were for use as touchpad equivalent. The combination of conductive thread and ink seem to be particularly interesting, see Figure 9 and Figure 10.
Basic layouts for functionality are described in Gilliland et al. [47]. They include patterns for rocker switch, menu, and electronic plead. Zeagler et al., [48] introduce the jog-wheel patterns. Evaluation results seem to indicate that multi-touch may have ergonomic disadvantages over direct manipulation [49].

We have to make sure, if we use such embroidered design patterns, that they allow for graceful degradation from the HoloLens application or use it only to operate the additional functionality.

Should not:

- replace UI AR elements in the HoloLens
- risk introducing complexity / sources of error

Could be used for:

- on-off button
• check and cancel button can be a failsafe where voice interaction (noisy environment) and gesture interaction (alternative to clicker) fails
• may be a quick solution for ‘warming up’ the sensors
• have a start / stop button for recording
• would have to be very reliable
4. Discussion

In the previous sensor selection process (reported in D3.1) associated with the first wave of the WEKIT trial, we selected Microsoft HoloLens [2] (see 0) for smart glasses and Myo [51] for hand/arm gesture recognition. In addition, we also selected a Sensor Processing Unit in the form of a Stick PC.

For the second wave of the WEKIT prototype, we have decided to not use the current generation of EEG sensors owing to noise associated with electrical interference in the use case scenarios at Lufttransport. Leap Motion [52] is also not considered at it requires high-speed processor and USB 3.0 ports for AR applications, this makes it difficult to use in a low energy and low processing power wearable prototype.

In this section, we make recommendations for the second wave of the WEKIT prototype with respect to the choice of microcontroller, the associated state-of-the-art sensors, power supply, and communication.

4.1. Recommendations for microcontroller

Based on the requirements of this project, we would recommend ESP32 microcontroller. For a smooth collection of data associated with different sensors operating at different frequencies more than one ESP32 can be used. Please note that ESP32 is available as Sparkfun EPS32 Thing, Adafruit’s Wroom ESP32, Wemos’s LOLIN32, and ESP32 Development boards with embedded OLED display [53] from other vendors also. For the proposed WEKIT prototype, ESP32 with integrated OLED display enables us to display information about the current state or the processes running on the microcontroller, thus eliminating the need for an external display. Hence, among the different models of ESP32 across different vendors, ESP32 with integrated OLED display is a better choice (see Figure 12).

![Figure 11. Microsoft HoloLens [45]](image)

![Figure 12. ESP32 with display [5]](image)
4.2. Recommendations for sensors

Based on compatibilities with Arduino ESP32 (operating voltage range of 2.3V to 3.6V), in Table 8, we summarize a list of recommended sensors that can be used for the second wave of the WEKIT prototype. Please note that for sensors such as IMU, temperature and humidity sensors, and vibration motor, there are other alternatives that can be chosen from Table 4 in Section 2.4. The alternatives have been marked by (*) can be selected from different vendors.

Table 8. Recommended sensors

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Product/Vendor</th>
<th>No. of units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate sensor (Ear clip)</td>
<td>Grove - Ear-clip Heart Rate Sensor [11]</td>
<td>1</td>
</tr>
<tr>
<td>Vibration motor*</td>
<td>DC3V 0834 Mobile phone micro flat vibration motor [15]</td>
<td>2</td>
</tr>
<tr>
<td>Galvanic Skin Response (for lab testing only)</td>
<td>Grove - GSR Sensor [16]</td>
<td>1</td>
</tr>
<tr>
<td>IMU*</td>
<td>SPI /I2C GY-9250 MPU 9250 [18]</td>
<td>2</td>
</tr>
<tr>
<td>Environmental temperature and humidity sensor</td>
<td>Temperature and Humidity sensor - SHT1x [20]</td>
<td>1</td>
</tr>
</tbody>
</table>
4.3. Recommendations for power supply and communication

For supplying power to the SPU and ESP32, and the associated sensors, we recommend to use a power bank with 5 V specification and two USB charging ports and a split USB cable with two port extension (see Figure 13). This way we can supply power from the power bank and send data between the stick PC and ESP32 via USB. For powering the stick PC additional USB connection with the power bank might be necessary, hence we recommend two USB charging ports power bank. Furthermore, we recommend transmitting the sensor data from ESP32 to SPU via USB serial link as it is quite reliable, can work in noisy environments, enables offline operation of the WEKIT platform and allows Wi-Fi module from the SPU to be used for other purposes. It is important to note that this setup should be thoroughly tested before implementation.

Figure 13. USB dual port splitter cable, one for power and other for data [28]
5. Conclusion

In this deliverable, we take into account the results from the trials associated with the first wave of the WEKIT prototype (from D3.2 and D3.3). Based on the results and discussions in a technical workshop at Heerlen (20 and 20 November 2017), we propose a final set of requirements for this phase of the project and provide an overview of a set of sensors that can be used to meet the requirements and needs of this project. Based on the overview, we give a set of recommendations that can be used for the development and integration of the final version of the hardware and software platforms. The recommendations include a microcontroller and the associated state-of-the-art sensors, power supply, wiring and communication mode that can be used. These recommendations will be used by the later deliverables of the WP3 and WP5.

It is noteworthy that our recommendations are compatible with likely future requirements of wearable devices, including both needs that are in scope for WP5 and needs which are out of scope for this project but will surely be in scope for large-scale commercialisation. An example relevant to RQ1 is having sufficient processing power to be able to undertake real-time combining of data from multiple sensors. Thus, selecting sensors to facilitate deductions of the context of use of a given sensor may require synthesizing information from sensors thought of as disparate data sources. Examples of such data combinations are:

- Biofeedback (e.g. from heart rate + GSR + EEG)
- Posture (from gyroscopes + HoloLens tracking + MYO armband)

Out of our immediate scope, but predictably important post-project, will be adding a data-policy layer to the sensor architecture, to limit the sensor-based deductions that can be made about a training domain and its users. A non-training analogy would be alerting users to the use of their sensor data by unauthorized people in an unexpected way, e.g. to construct a GPS trail to monitor the location and identity of people near to a user [54].
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