Usability and Engineering Aspects of Competing RF Technologies for Communication with Commercial Sports Sensors in Ubiquitous Applications

Experimental Comparison of Power Consumption and Use Cases for ANT+ and Bluetooth Low Energy Sensor Devices

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Abstract: the commercial market offers quite some time already personal electronic sports tools for control and monitoring of physical workouts. With these units, body measures like movement speed, tread rates, and heart rate are detected by tiny autonomous sensor units and their recordings are transmitted via RF for further processing to a central handheld device. Since a while, also smartphone apps can be used as control instance, if their ubiquitous host device supports one of the particular RF standards for coupling them to the sports sensors. During the last decade, two competing wireless standards have evolved for this sensor air link, which are called ANT+ and Bluetooth Low Energy. The key features of this remote communication technology determine the usability within the various scenarios in personal sports, for instance the question how many sensor devices can be operated closely to each other without interference. In this paper, the specified and advertised properties are analysed on base of the definition of these RF standards, and they are furthermore practically verified with experiments. In particular, measurements of power consumption are shown for the two different RF systems, since life time of sensor battery has relevant impact on convenience of daily use. Furthermore, practical observations of various spurious effects when using the two RF standards are reported here, which seriously bring the reliability and accuracy of such commercial devices into question.

1 INTRODUCTION

Aging societies and also overweight, which can be nowadays observed often already for young children, induce continuously increasing costs in public healthcare. This kind of evolvement especially applies to the developed countries (Colagiuri et al., 2010). Accordingly, efforts are gradually intensified for encouraging broader parts of the citizenship to regularly perform more physical activity (Valentín and Howard, 2013), because its positive effect is known and verified already from decades of scientific research (Wannamethee and Shaper, 1992).

Addressing the application field of sports and fitness tools, over a period of time a broader market has evolved that supplies appropriate computerized tools for this purpose. In particular, monitoring and control of physical workouts can be performed on base of sensing the activity situation and condition of the human body, such as measuring heart rate, body temperature, acceleration forces and movement speed. Blood glucose level or blood pressure would also be measurable by such commercialized devices, but these are applied less commonly. In addition, various sensors can be attached to sports machines like cycloergometers for complementing the trace of physical activity of sports people.

Such tools are also of interest for semi- and full-professional sports, since the relation between the easily measurable parameter of the heart rate and the physical effort level has been verified already long time ago in medicine (Hoppeler et al., 1985), and later also in sports research (Arts and Kuipers, 1994). Certainly, heart rate monitors are the overwhelmingly advertised commercial tool for personal sports and fitness activities, but many athletes complement this type of body sensor with sensors for tread or stride rate and style for reaching best sports performance.

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Figure 1: Body sensors for tracing sports and fitness activities. Upper left shows the circuit board of a footpod, while the other three devices are heart rate sensors. *A* works with the RF standard ANT+, while *B* and *B+* are using Bluetooth as printed on their plastics case.

The general construction concept of such electronic toolsets for personal sports monitoring is, that data is collected by autonomous body sensors (Fig. 1), which transmit their measures to a central control unit via any kind of near field RF link. As typical control device a watch like computer is used (Fig. 2), or other tiny constructions that can be either worn easily by a sports person, or which can be mounted on a sports apparatus like a bike or similar. A blocking aspect is, that such control units work with closed software systems, which can not be easily modified or even replaced with any other customized implementation. The situation is quite similar to the first generations of mobile phones, which also contained fixed operational software systems.

Figure 2: Two commercial sports units and one Android smart phone receiving the identical ANT+ signal from a heart rate chest strap. The left most device is for bicycling, the middle one is a Triathlon watch, and the smart phone app was developed in a usability study on sports utilities.

Fortunately, some of the important vendors for electronic sports devices agreed roughly a decade ago with the so-called ANT+ system on a common communication standard that shall provide seamless interoperation (Dynastream Inc., 2011). Later, the Bluetooth consortium also expanded its own definitions towards the so-called Bluetooth Smart standard (Bluetooth SIG, 2015), which stands for a very low power consumption in the communicating devices, and which makes it also feasible for the battery cell operated sports sensors.

In former research, this opportunity was used to investigate, how the user handling of the control handheld can be made more convenient, in particular for applications in semi-professional endurance training (Weghorn, 2015.1). In the beginning of this project, ANT+ had to be used for coupling the sensors to the control software, which was realized on Android smartphones (visible in Fig. 2).

Half a decade later Bluetooth LE experienced its broad market introduction within the smart phone segment. For a technological evaluation on software engineering efforts for the two alternative systems (Weghorn, 2015.2), a simplified heart rate monitor for an Android smartphone was developed (Fig. 3).

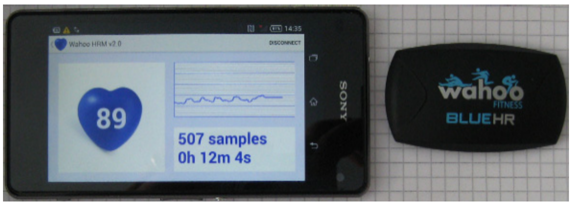

Figure 3: Simplistic Bluetooth LE heart rate monitor running on an Android smart phone. This was developed earlier for exploring the software engineering process and it was used in the experiments described here.

From this experience in developing heart rate monitors and the observation with the sensor systems using the two competing RF communication standards, additional, new research questions arose, because both RF consortia can be understood as offering the "better" standard. One field of interest are the possible use scenarios, where these sports tools can be efficiently employed for best benefit of workouts. This addresses personal use with one single or with several sensors, as also the use within a group of sports people. In this paper, these aspects are discussed and the findings are complemented with a helpful base of practical experiments. In particular, during the many hours of experiments on power consumption different spurious and critical effects in the sensor operation have been detected. In the end, this paper can report about features and usability of commercial sports tool sets with special scope on the two competing wireless standards for sports sensors.

2 ANALYSIS OF THE RF SPECIFICATIONS

In a pre-investigation, the properties and features of the two communication standards have been analyzed already (Weghorn, 2015.2). According to these, ANT+ works with a straight forward 32 bit addressing concept for its nodes. Considering the most typical sensor of a heart rate detector, this device class broadcasts its measures automatically after detecting source signal (what happens, when it is attached properly to a human body via a chest strap). Broadcast of sensor measures implies that the information can be consumed by many devices in parallel without mutual disturbance (Fig. 3).

This seamlessly maps to training cases like a sports person using a sports apparatus, which is connected to the personal heart rate sensors and at the same time a recording to the personal device, e.g. a smartphone, is running. Or even more, a coach could easily surveil the activity of this sports person remotely from another, additional control monitor.

In contradiction to that, Bluetooth LE follows in its communication a master-slave principle. This consequences, that the working of the sensor and the RF link has to be initiated in a point-to-point scheme, and the transferred information cannot be consumed directly in parallel by other devices. A parallel use of sensor information is not totally excluded, but it would require that the control device, which is talking to the sensor as master, would have to register itself as a sensor slave for other Bluetooth masters. In this sense, it needs to work as repeater of the information to other so-called micro network cells, which indeed can coexist in Bluetooth. Of course, this will complicate the programming design of the control device software considerably, and the handling would be moreover rather inconvenient, because a manual pairing between two communication partners is mandatory at least once for the operation of each of the parallel Bluetooth link.

Another exercise scenario is monitoring a group of people during, e.g., indoor cycling. With ANT+, it would be possible to supervise the activities from a central device that is handled by a coach, while Bluetooth limits the number of nodes within a micro cell to 8, so the central device could only trace 7 people in parallel, and also only if each sports person is using just one single sensor (e.g. for wheel turning speed, or effort level). Again software constructions of setting up parallel micro cells could solve the problem, but it will also increase the construction efforts for the central unit.

Doubtlessly, the most common use in sports will be a 1:1 scenario, where a sports person is using the personal body sensors together with one control unit, e.g. a smartphone, in a rather private environment. Both RF standards, ANT+ same as Bluetooth LE, are clearly capable of serving such a scenario, while the elaborated use cases are only reasonably functioning with ANT+.

Discussing further the specifications shows that ANT+ and Bluetooth LE are both transmitting their information via radio in the royalty-free ISM band. Both cocnepts are aiming towards very low power consumption, which is primarily reflected by a low sending level of 1mW. That the sending strength is identical for both standards can be seen from the measured signal strength in experiments with the two standards (Fig. 4 and Fig. 5).

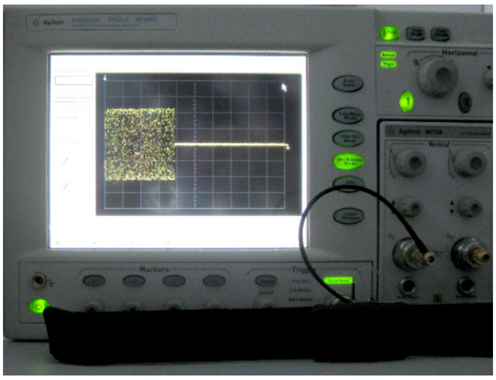

Figure 4: RF measurement of the ANT+ transmission frame of a heart rate sensor. The oscilloscope was set into accumulating mode for this measurement, the time scale is 50µs per display square unit.

The bits are modulated with a the GFSK scheme (Gaussian frequency shift keying) in both RF systems. According to the protocol for addressing and node identification in ANT+, the minimum frame size is here 175µs, which was verified by a RF measurement of the sending signal (Fig. 4). Since the used heart rate sensors add extra information (in particular one extra byte for battery voltage) on top of the minimum sensor frame definition, the observed frame length is here 190µs.

Surprisingly, the frame length of the Bluetooth LE measurement didn't map directly to the specified frame size of 650µs (Fig. 5). Analysis of the measurement yielded that the sensor device transmits two sub-frames for each of its measures, which sum up to a total air time of only 350µs. This Bluetooth LE behavior was recorded for an established and working life connection between the heart rate sensor and the control unit, while it was observed that after loss of this connection the sensor indeed used the nominal RF transmission frame length of around 650µs.

Another effect will increase Bluetooth consumption on air further: in case of channel collisions, re-transmission is invoked in Bluetooth, while ANT+ ignores any channel collisions. ANT+ uses one single carrier frequency out of a set for one particular sensor and tries to avoid collisions by a gradual shifting of the sending time frame. Since 2^{16} nodes can co-exist in the available band locally, the likelihood of true collisions is rather low, which is unlike for Bluetooth. It can be expected that in an environment, where many sports user and by that many active Bluetooth micro cells co-exist in the same RF visibility range, there arises an increase in power-consumption and sometimes an irresolvable interference due to the much lower count of possible independent air links.

What can be concluded here already from the standards is that ANT+ consumes approximately half of the energy than Bluetooth LE within the plain air transmission.

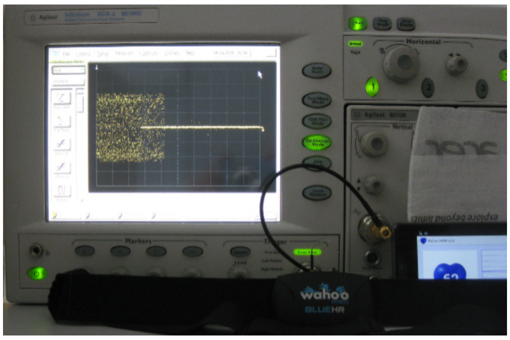

Figure 5: RF measurement for Bluetooth LE.

3 EXPERIMENTS ON TOTAL POWER CONSUMPTION

In practice, measuring the lifetime of a tiny battery cell faces different difficulties, especially for pulsed devices with very low average consumption. A direct measurement of supply current during use of the sensors is impossible, because the measuring equipment can not be worn during sports (even a miniaturized, remote controlled ampere meter wouldn't be feasible because of the restriction to local use). Therefore, an indirect measurement cycle was selected:

1. Measure the battery voltage
2. Use the sensor device actively for a defined period of time
3. Measure battery voltage again and detect by that the discharging amount

According to the experience on battery lifetime from sports exercises that was collected over many years with ANT+ sensors, a usage time of 1 hour was estimated to produce on the one hand side a measurable effect, while remaining on the other side in almost linear region of the discharge curve (Varta Microbattery Inc, 2015).

Specific experimental configuration and results

For this first experimental set, one ANT+ heart rate sensor and one Bluetooth LE heart rate sensor were used, which were both operated from a lithium cell of the identical standard type CR2032. For this experimental series, two fresh cells were manually selected out of a bigger lot from the same quality vendor for providing an identical free starting voltage (3.243 Volts for both). The two cells are named here and in the following sections X and Y.

For such lithium battery cells many data sheets exist, which display their capacity in dependence of various parameters like, e.g., discharge current and temperature. Unfortunately, no information is available about the capacity tolerance. Since the cells produce their electrical supply by a chemical reaction process, which is similar to the one in other electronic parts like electrolyte capacitors, it can be expected that also such battery cells do suffer from similar considerable variations in the order of at least several percent. The starting voltage, of course, doesn't state anything about the precise capacity, and the following concept was worked out for compensate this error factor during the comparison of the sensor consumptions: For the two sensors from Fig. 1 called here A (ANT+ sensor) and B (Bluetooth LE sensor), the batteries were used in alternation according to a balancing time slot scheme (Tab. 1).

Table 1: Swapping plan for battery cells X and Y while measuring after each hour (= time slot) of use their discharge voltage caused by the sensors A and B.

slot	1	2	3	4	5	6	7	8	9	10
X	*A*	*B*	*B*	*A*	*A*	*B*	*B*	*A*	*A*	*B*
Y	*B*	*A*	*A*	*B*	*B*	*A*	*A*	*B*	*B*	*A*

According to the battery data sheet it is supposed to keep in this plan all discharge voltage differences at linear scale. While performing light physical exercises during the hours of sensor use, the discharge voltages were determined for four cycles only (Tab. 2). The sensors were attached during the time slots to the same person, so that there was no possibility for systematic error influence by different sensor loads. The reason for completing the experiments with less cycles than in Tab. 1 was, that there was already a conclusive difference visible between sensors *A* and *B* with fewer runs.

Additionally, it has to be regarded that the Bluetooth sensor *B* was sending measures at varying and at lower frequency of at maximum 1.8 seconds/samples, while the ANT+ sensor *A* was broadcasting its measures at a fixed rate of 0.5 seconds/sample.

Table 2: Trace of the voltages while gradually discharging and swapping batteries between sensors. Obviously, one sensor is unloading the batteries considerably faster than the other.

	battery *X*		battery *Y*	
	Vx	dVx/dt	Vy	dVy/dt
t = 0h	3.243V		3.243V	
t = 1h	3.206V	-37µV/h	3.158V	-85µV/h
t = 2h	3.129V	-77µV/h	3.148V	-10µV/h
t = 3h	3.051V	-78µV/h	3.122V	-26µV/h
t = 4h	3.022V	-29µV/h	3.065V	-57µV/h

From the record of the discharging voltages in Tab. 2, the total load for the two sensors can be resolved by the battery cell use as listed in Tab. 1. The total discharge load within the four hours of use for the ANT+ sensor is calculated to:

$$-\Delta V_{Atot} = 37\mu V + 10\mu V + 26\mu V + 29\mu V = 102\mu V$$

And the calculation for the Bluetooth LE sensor yields as total sum:

$$-\Delta V_{Btot} = 85\mu V + 77\mu V + 78\mu V + 57\mu V = 297\mu V$$

Intermediate synopsis of discharge experiments

From this collection of experiments various intermediate results can be derived: First, the time slots of 1 hour appear long enough for detecting the discharging effects. Second, the two battery cells behave differently, hence the assumption that the batteries are varying in capacity is also validated. Third, the discharging steps show, that the measurements do have bold error bars, so the precision of the measurements appears limited. Despite the the experimental restriction, it is systematically visible, that the ANT+ sensor consumes less energy than the Bluetooth LE one. Despite that the ANT+ sensor is working more than three times faster, it requires approximately three times less electrical energy in average.

The measurements have also shown that it is rather difficult to obtain systematic and reproducible results with these electro-chemical power sources. When not in use and removed from the sensors, the cells use to recover within hours and days, so stable voltages and differences in the order of µVolts couldn't be validated in longer terms. Therefore, two more experiments were conducted, in which the ANT+ sensor was used for several hours and without removing the battery and giving a chance for self-recovery of this battery. Accounting for all three experimental runs, the average discharge rate of the ANT+ sensor at a sample rate of two heart rate measures per second was found being

$$dV_A/dt = 18{,}83\ \mu V/h \pm 5{,}8\mu V/h$$

Estimation of total sensor battery lifetime

Under the assumption of a usable battery voltage range from 3.3 Volts (fresh cell) down to 2.0 Volts (cutoff limit for empty cell), a battery lifetime of roughly full three days for the ANT+ sensor can be estimated. The Bluetooth LE sensor will work only for one single full day. All this is much behind the advertisements of the consortia for these RF standards, who advertise continuous work of sensors for even several years with one single fresh battery.

It has to be stated that the Bluetooth LE technology experienced its market introduction half a decade latter than ANT+. The used Bluetooth LE sensor *B* (Fig. 1) is one of the first generation that was feasibly working with smartphones again of a first device generation, which supported the Bluetooth LE standard. On the other hand, the description on the boxing wants to make suggest that this is technology provides a long lifetime of sensor battery, which is obviously misguiding.

Comparison of different product generations

At the end of the experiments, another Bluetooth LE sensor was purchased (*B+* in Fig. 1), which stands for a recent product generation of a quality vendor for electronic sports equipment. This sensor, which shall be called *B+* here, has got another type of supply battery, therefore the discharging experiments can not be applied in the same way like described here, since a swap of batteries between the sensors is impossible.

First investigations have shown that the discharge rate ranges with approximately 28µV/h in the similar order like the ANT+ sensor, so it is considerably less than the Bluetooth LE sensor of the first generation. Also the energy saving scheme by automatic deactivation works reasonable for *B+*, because it shuts the RF transmission down, when the input signal is lost for more than 20 seconds. On the other hand, it also comes also up with increased RF activity, if no host Bluetooth connection is enabled, or if such an air link is suddenly terminated despite it was established and working before. The construction of $B+$ suffers from a more bulky case (20% thicker), 50% more mass, and this all despite a smaller battery.

Summarizing the experimental findings here, it can be stated that ANT+ appears as efficient as or even better than Bluetooth LE, when targeting a longer lifetime of sensor battery.

4 OBSERVATION OF SPURIOUS SENSOR EFFECTS

Naturally, any body sensor for human activity has to be operated under appropriate conditions before reliable measurements can be expected. One base requirement, of course, is sufficient power supply, which implies for the sports sensors a battery that is still sufficiently loaded and provides more than a minimum, well defined supply voltage. For acceleration sensors, the proper mounting, e.g. at a running shoe, has to be ensured, for sensors determining heart rate good and appropriately placed electrical contacts to the human body are mandatory.

Observation of unpredictable distorted measures

During several years of practical use, various problems have been observed many times, despite such sensors were thoroughly attached and used. Those disturbances couldn't be investigated, since they arose unpredictably and intermediately only. Suggestions for the reason may indeed be problems with electrical contact quality, but also RF interference from unknown other sources come into question. With several, different ANT+ sensor devices, spurious heart rate measures have been recorded occasionally. Sometimes the disturbances appeared only for a short period, sometimes some kind of pattern could be interpreted into the data (Weghorn, 2015.2).

The ANT+ sensors also produce wrong, much too high measures, if battery life time is reaching its end. Unfortunately, the sports computers do not appropriately evaluate the battery information from the ANT+ transmission package - an important parameter that is a defined by standard - but the data is processed further without any notification, also disregarding that sometimes measurement values appear even in a non-physiological range. Both effects could be easily handled by adequate software controls and algorithms; hence, the lack of such mechanisms can be considered as serious deficiency, which labels the commercial sports devices as not elaborated to the state of technology and unreliable.

In Bluetooth there is not even a clear definition for mandatory information about power supply voltage of the sensor, and consequently such safety checks are not necessarily available at all. This represents also a clear defect in design of the standard. Taking oscillograms of the RF packets unveiled even further worse sensor effects.

Nonsensical replication of sensor data samples

First of all, from the users point of view, it can be observed that sensors keep on repeating the last measures, in situations were the sensors is have lost their input signal. For instance in Bluetooth LE, a heart rate sample is passed to the control software through the communication instances, despite there is no input signal any more for a very longer while. The continuation of replicated values applies for Bluetooth sensors as also for ANT+ sensors at least for a shorter while - the minimum time for detecting signals loss was in the experiments 20 seconds - while an older Bluetooth LW sensor kept on sending information packets for three hours and further on (Weghorn, 2015.2).

In a side experiment on the behaviour of the Bluetooth communication it turned out, that spurious measures were further replicated even within the control unit, despite the fact that the air link was out of range. A simultaneous observation of the sensor behaviour with the oscilloscope showed in this experiment, that the sensor well was capable of detecting the loss of connection, but the communication protocol stack on the handheld control unit kept on producing spurious values.

A further effect was found as another side observation during the comparative evaluation of the power consumption. The Bluetooth LE device followed the ANT+ measurements by a short delay, sometimes this delay increased to a several seconds. In heart rate monitoring this kind of behaviour may not be too critical, because variations of heart rate are physiological in the order of seconds. If the same effect occurs with sensors for wheel turning or stride rate and style in running, swimming or other activities, it wouldn't be acceptable, because it distorts any possible analysis. Additionally, the impression was that the two heart rate measurements taken simultaneously from the identical person by both RF systems often didn't match exactly, even when there was no variation in activity. This suggests another conclusion, namely that the measures are imprecise in general. From the experiments so far it can not be decided, which sensor system has which error strength, this would be a research point for further detail investigations.

In summary, these observations lead to the impression that the technology is not handling sensor problems reasonably, it even more arises the suspicion that the sensor concept intentionally hides recording as also communication problems.

Summarizing quality assessment of sensor data

This all guides in sum to the judge that information from sports sensors is delivered unreliable and that the measures can be disturbed unpredictably at any time. Even worse appears the fact, that intelligent processing itself often can not recognize faulty situations, and therefore it is not possible to develop appropriate software intelligence that is able to inform the sports user accordingly. Such system behaviour may in the end also easily lead to misinterpretation of workouts.

5 CRITICAL REFLECTION ON ENGINEERING

The tool sample of heart rate monitoring, which was used in the experiments here solely, represents just one particular application in sports, but it can be considered of being representative as a common and typical one for the investigated low energy RF communication standards. The reason is that heart rate monitoring is based exactly on the same scheme like for other common sensors like foot pods, pedal tread rate sensors and speedometers for bicycles.

In this sense, its operational scenario reflects the use of just one autonomously operating sensor, which is broadcasting its measures along the time axis. Advertisements in the low price class market for electronic sports tools show that heart rate monitoring is exactly what is offered mostly in an extremely broad price range for the end products, and it is also a feature for any more elaborated sports watch or computer. Evidently, bringing this functionality to all-world devices like smartphones will support even more customers to use it.

Use cases and limitations in sports scenarios

Very typical is also the role for the heart rate sensor as network node: either it serves as source in a point-to-point link – one sensor and one sports computer – or as point-to-multipoint – one sensor broadcasting at the same time its information to many consumer devices, e. g. simultaneously to a personal smartphone, a sports machine and the surveillance monitor of a coach. Both modes should work automatically, even more a seamless transition between these modes can be expected according to the current state of technology.

This investigation clearly shows the limits of the Bluetooth LE system in comparison to the ANT+ concept. In particular the power consumption measurement also shows the better performance of ANT+, but it has to be stated here, that this can be also effect of an old device generation as the first experiments with the newer sensor indicate.

In total, the discharge experiments may be too critical, because the recovery behaviour of the lithium battery cells was not studied and by that regarded in very detail. Three days lifetime for a new battery in an ANT+ sensor appears really low and doesn't map many days and weeks of personal use of such sensors in sports, which was not scientifically investigated. At least, the findings can be considered as reliable infimum for the battery durability.

Overcoming the need for sensor batteries

Looking at modern and future development in tiny electronics, the research question about battery lifetime has to be challenged anyway. It is not appropriate any more to use batteries at all in the very low power sensors, instead super capacitors should be the first choice as energy source in such devices. From the consumption measurements it can be derived that a capacity of 3mF per operational hour would be required. The capacity of low voltage gold capacitors range in the order of 100 times this value at a lower price than for lithium battery cell, but at a similar size. The super capacitor can be loaded contactlessly through a magnetic field. Or in case of the heart rate sensors even the body contacts can be used for DC injection during charging. This would make the use of the sensors more comfortable also in mechanical sense, since the exchange of the tiny batteries with even more tiny screws is often not easily possible without special mechanical tools.

6 CONCLUSIONS

Two different RF standards are nowadays available and commercialized for wirelessly binding body and activity sensors in sports applications to handheld control units. Especially the use of smart phones for the latter purpose may make sports exercises to a regular part of the weekly life cycle also for average people. Doubtlessly, if such workouts are monitored and controlled properly - that is, what could render possible because of the broad availability of the before described devices - there can arise positive effects on the average health and fitness level for broader parts of the citizenships.

In this study, the usability and reliability of sensors working with the two competing RF linking standards ANT+ and Bluetooth have been investigated. The results are not strictly positive; instead there arise many problems in daily operation. First of all, the battery life time is much lower than what is promised by the promoting consortia of the two RF standards. An early hardware implementation of a Bluetooth LE sensor appears much worse than ANT+, while newer Bluetooth sensors may reach similar operational times.

ANT+ is the standard of the two that is basically parameterized for lower energy requirements on the air link, but the consumption measurements have shown that the leverage of the sensor electronics is much higher than just the contribution for the RF transmission. Even more energy is wasted, if the sensor sleep mode is not controlled properly by its own firmware. In particular, the older Bluetooth LE sensor kept on being active for hours despite control link and body contact were lost. As RF measurements show, Bluetooth produces an increased air activity - and by that a much increased energy expenditure - when the host control connection is lost or shut down.

Directly notable by the sports user appears the network node design in both standards. While ANT+ allows a lot of nodes being operated close to each other, and while it furthermore enables a seamless interoperation of one sensor with many parallel consuming devices, these features are not available with Bluetooth LE. Hence, it can be expected that there are many interferences, when Bluetooth LE sensors are operated in gym studios or in bigger sports events like, e.g., city runs. Even worse appears the fact, that the sensors and display units hide communication problems by simply replicating the last valid sensor measure. This effect may occur even for several hours despite the sensors are detached from the body.

Also other spurious measures have been observed from time to time in various use situations. In addition, it was found that measures from Bluetooth LE sensors were displayed considerably delayed compared to ANT+ sensors. Accordingly further research is planed in this context here, where professional instruments - e.g. a wired medical ECG recorder - will be used to evaluate the precision and time-axes accuracy of the commercial body sensors feasible for RF linking to smart phones.

Summarizing the current situation of an average sports user, who is not a technical expert and who wants to apply the available commercial tools for the best control and benefit of physical workouts, it has to be stated that no clear recommendation for one particular system can be given. ANT+ seems to be the technology that is better appropriate for versatile and professional sports applications, while Bluetooth LE experiences a much broader support due to the compatibility to almost any new smart phone. Further research on the sensor data will unveil, whether the Bluetooth LE combination can be considered as a professional sports tool or just as a nice-to-have rough measuring indicator that gives some inspiration for sports activity.

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