Swim like a fish with AI

Combining AI and sensors to create a new generation of intelligent wearables

Kaustubh Gandhi, Senior Product Manager Software, Bosch Sensortec
www.bosch-sensortec.com

November 2020

Artificial intelligence (AI) is rapidly becoming a natural and integral part of our everyday lives – working silently and unnoticed in the background. AI makes sense of the multitude of data streaming in from various sensors to deliver detailed and precise insights, which have the potential to increase the utility of virtually all electronic devices on the market today. This defining technology can accurately determine whether the user of a device is walking, running, sitting, sleeping – or even swimming in real-time. This article explores how sensors synergize with AI in wearables to deliver valuable information to users – even in demanding environments like swimming pools.

Artificial intelligence (AI) is becoming an increasingly more common element in both existing and new applications and products. The power and potential of AI is especially significant when it is applied to data collected by the highly precise sensors housed inside today's consumer devices. A classic example is a wearable device such as a fitness wristband or smartwatch, where AI is able to determine what the wearer is doing at any particular point in time, like walking, sitting or sleeping – with a high degree of accuracy.

The secret ingredient, however, is leveraging the power of machine learning for activity classification by which device manufacturers can substantially increase user engagement and value for the users. With AI it is possible to systematically consolidate the behavioral characteristics of a wide variety of users performing activities in different usage and environmental scenarios. Thus, an AI driven system can improve the accuracy of an end device's outputs. Using the example of a swimming tracker, this article examines how AI can turn sensor outputs into compact resource-saving actionable data.

Tailored wearables offer attractive market potential

While standard fitness and activity trackers have now become commodity consumer products, wearables tailored to swimming motions have been neglected to a certain extent. Due to the many individual characteristics exhibited by people and their varying swimming styles, there exist several limitations to traditional, non-AI software development approaches. Therefore, this presents a potentially lucrative and unsaturated market comprising of an estimated 300 million of regular swimmers and athletes worldwide willing to purchase devices for tracking their performance reliably.

The dynamic swimming environment is an ideal 'proving ground' for demonstrating the power of combining motion sensors with advanced AI algorithms in a real-world setting. An intelligent, self-learning swimming wearable should determine swimming speed and distance and provide valuable information about the swimmer's technique and identify any weak spots such as slow flip-turns or stroke rates. This key information should help the swimmer, coach or even parent to identify where technique or fitness requires improvement.
A survey conducted in 2018 of regular and professional swimmers revealed expectations of what kind of device would be desired. The responses included that swimmers prefer a private system, which does not need to be connected to the internet or to a cloud to ensure data privacy. The solution should be a part of a single, existing accessory, such as a wristband or watch since the users do not want to manage additional electronic devices. It should have its own unobtrusive, automatic tracking, as well as precise reporting on specific improvements in regular swimming performance. Finally, the solution needs to be affordable for the user, which implies that AI systems should run on the microcontroller instead of a graphic processing unit (GPU), traditionally used for AI in order to save costs.

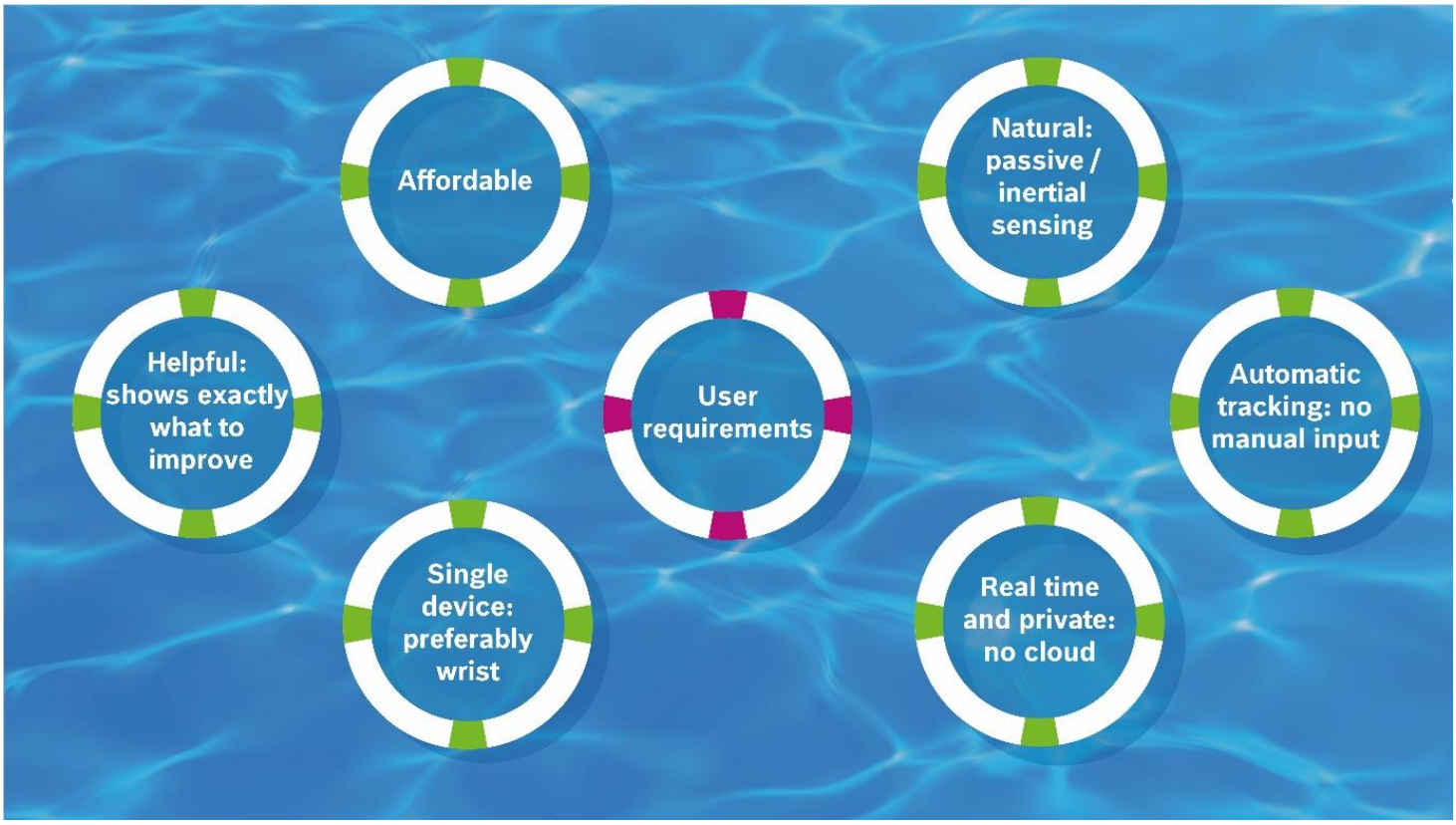

Figure 1: User requirements for swimming wearables

Limitations of current swimming tracking solutions

Most of the current swimming trackers either do not provide adequate useful information, such as swimming efficiency, for improving performance or provide it with cloud-based analytics, which are costly and lack privacy. Consequently, rather than 'play with gadgets', serious-minded competitive swimmers will pay money to professional coaches or use expensive camera-based systems to analyze and improve their performance.

The swimming tracker needs to be able to accurately and reliably classify movement 'in-situ in real-time', stroke by stroke over the course of the entire training session. However, inherent economic viability factors come into play, which result in real limitations. The manufacturer of a device is thus forced to compromise or balance out and optimize the cost and capacity of components, transmission, storage and processing capability without adversely compromising classification speed, accuracy and reliability.

If all the collected data were to be transmitted to the cloud and processed remotely, the data bill for the user would be very large, which would significantly dampen the device's appeal. In practice, device manufacturers can provide a 'free' cloud service and bundle the projected lifetime cloud costs into the up-front purchase price of the wearable device, which again prices most potential users out of the market. Advertising or data sharing may provide an alternative, however, many users would consider this to be an intrusion into their privacy.

The high-performance, wireless or RF connectivity modules installed in the wearable further increase the costs of any cloud-based solution. Not to mention the required non-stop internet access or smartphone pairing, which is not always physically possible. Likewise, storing all the collected sensor data on the device adds another layer of cost, while the required powerful processor adds yet another. When combined, the cost, storage and processing factors turn this into a very expensive proposition, essentially unviable for mass market adoption.

Sensor data fusion to the rescue

The most straight-line approach to these obstacles is sensor data fusion, a process whereby sensor data from disparate sources is intelligently combined to derive accurate information. A processor is often integrated within the sensor itself, enabling sensor data to be pre-processed on the sensor module, thereby dramatically reducing the amount of data requiring storage and transmission to the cloud. This potentially eliminates the need for a cloud altogether. A huge benefit of this approach is that the main processor in the wearable device can be significantly less powerful, which further reduces costs.

To demonstrate the synergy between sensor data fusion and AI in real-world scenarios, Bosch Sensortec has developed and built a swimming tracker solution. It can be integrated inside the smart sensor BHI260AP. The BHI260AP is additionally equipped with other useful wearable features, such as self-learning fitness tracking, pedestrian dead reckoning and 3D orientation tracking, which can be enabled in the sensor depending on the need of user application.

The swimming tracker software uses real-time sensor data from a three-axis accelerometer and a three-axis gyroscope, both of which are integrated inside the smart sensor BHI260AP. Since it also features a powerful floating point microcontroller, it can provide both raw sensor data as well as run AI functions and generate relevant results for direct use by an application processor thus lowering system power consumption and processing needs.

First, the swimming tracker software uses motion sensor data to determine that the user has started swimming, without requiring any action from the swimmer (see figure 2). It then classifies the stroke type from four possible categories, namely backstroke, freestyle, butterfly and breast stroke. Subsequently the software records the number of strokes, laps and any breaks between the laps.

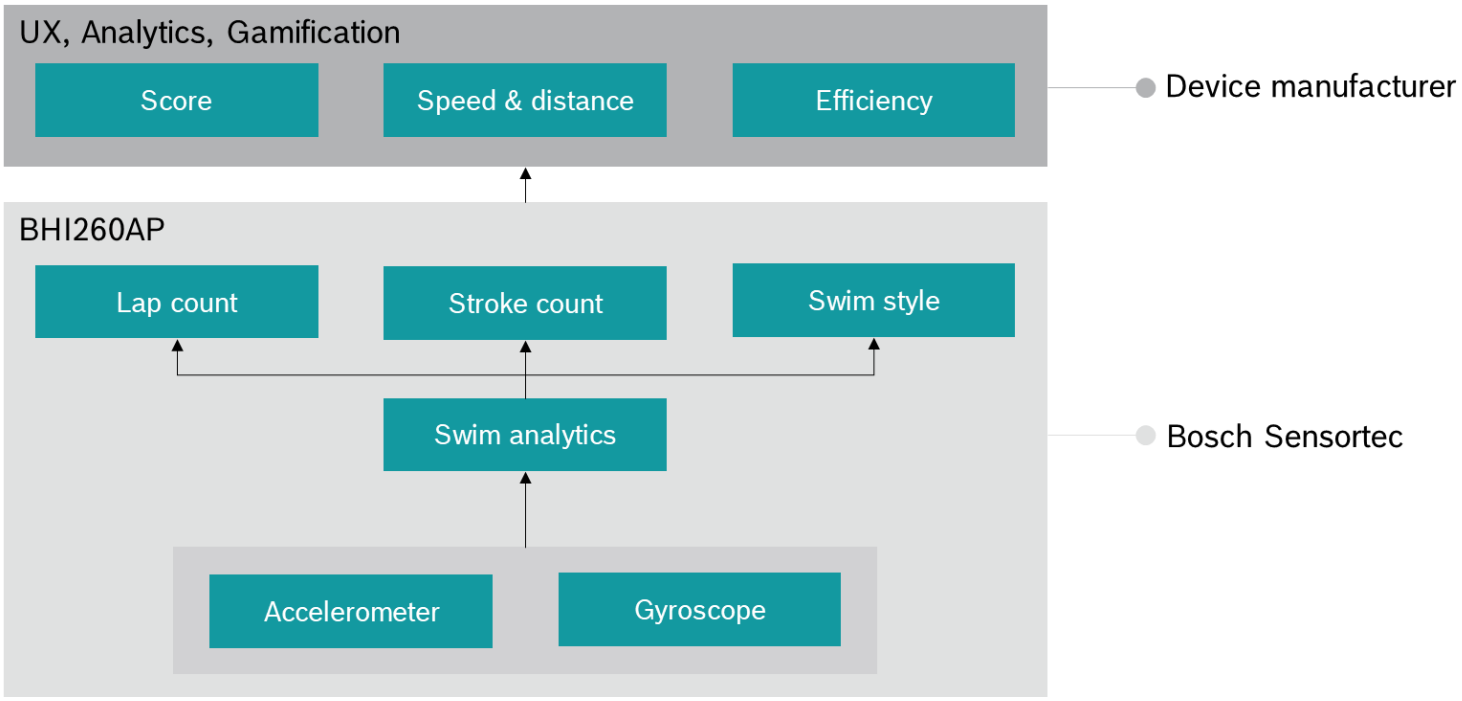

Figure 2: Swim classification software algorithm

Figure 2 shows how a wearable swimming device can use pre-processed data to neatly calculate information such as speed, distance and swimming efficiency. The provided data also facilitates the generation of a SWOLF (Swim Golf) score: a widely-used measure of swimming efficiency derived from the time spent swimming and the number of strokes counted. (*SWOLF = Swim Golf score; (No. of seconds + No. strokes) / Lap; Lower number is better)

This information enables swimmers to keep track of their performance and monitor improvements, while identifying weak spots needing specific training. They can also compare their data with their own historical data, friends, training partners or experts.

Achieving accuracy: the trade-offs

When talking to device manufacturers, they invariably all call out the single most important swimming tracker parameter: accuracy. To make their investment worthwhile, end users want a highly accurate product. Accuracy enables OEMs to offer a system that users can trust. In practice, satisfactory accuracy can be very difficult to achieve. Every swimmer is different in terms of height, length of limbs and the speed and power at which their arms and legs move through the water. In addition, as people swim with varying energy levels, the speed of arm movement may fluctuate considerably for the same swimmer during a given session.

This is where AI becomes essential. Developing a tracking solution tuned to the requirements of a 'typical' or 'average' person will not deliver sufficient accuracy. There are too many wide-ranging

variables. The key is that AI enables the wearable device to accurately detect and classify the swim strokes even if the user's specific characteristics vary. This enables the processed results, such as the number of strokes, laps and rest times, to be more accurate.

Due to this AI component and the many years of experience in this field, Bosch Sensortec in collaboration with experts from Bosch Corporate Research, has developed a solution that implements innovative signal processing, filtering and both classification and counting, all inside the smart sensor. For example, in classifying the type of swim stroke, this solution achieved an accuracy rate of over 90 percent, which is comparable to the best-in-class trackers available on the market today. Usually AI implementations targeting higher accuracy require deep learning on GPUs for processing and maintaining huge datasets. Bosch Sensortec's AI swimming software, however, runs on any smaller microcontroller.

As the AI software itself is data driven, depending on actual computational resources available and user insights, the manufacturers can trade-off functional accuracy against various soft-levers, such as latency (of detection), power consumption (MIPS of CPU and sensor data rate) and code size of software.

To drive user engagement, there are always some more trade-offs possible with AI. For example, manufacturers can choose to configure Bosch Sensortec software to track precisely based on a standardized style, or to adapt more specifically to the style of their chosen demographic based on region, age, etc. This also helps to offer standard or customized solutions for professional and amateur users.

In addressing all these trade-offs and compromises, there is no substitute for experience. As the technology leader of innovative sensing solutions, Bosch Sensortec has carried out many years of research and acquired real-world data for practical validation of theoretical concepts in actual user scenarios. This expertise enables the highest possible accuracy with limited computational resources, and effectively optimizes trade-offs in terms of cost, accuracy, size and power consumption.

AI delivers accurate, cost-effective tracking

With accurate sensors and AI-driven software, Bosch Sensortec can provide a more cost effective and private-for-end-users solution without compromising accuracy for swimming trackers. This product shows how AI enables wearable device manufacturers to build a differentiated, value-for-money product with reduced storage and processing costs, without expensive embedded processors, or deep-learning or neural network hardware.

With the core software provided as a plug and play solution, device manufacturers can develop their product faster, cutting time-to-market and reducing design and development costs.
In addition, they also have a high degree of flexibility to easily further develop the software, for example adding more swimming styles or customize it geographically with further support from Bosch Sensortec.

Overall, the above-described swimming tracker example demonstrates the benefits of using AI together with motion sensors and smart sensors in consumer electronics applications. These same principles can be applied to other wearable devices, such as step trackers or fitness devices. The combination of AI, motion sensors and sensor data fusion provides flexible, accurate and cost-effective solutions for new generations of smart devices.

What's next?

The swimming tracker solution described above is just one example illustrating the basic steps being taken on the long and exciting journey towards a world of applied artificial intelligence in consumer and industrial products.

The swimming tracker solution demonstrates the inherent strengths of AI: its ability to learn and to develop independently of human intervention, or at least the potential to do so in the not too distant future. With AI, swimming trackers may soon recognize and adapt to the age of the swimmer, their swimming style and technique to deliver information and analysis to enable constant improvement in technique and performance. Whether used in schools to teach swimming to children or in national sports institutes to support the world's finest athletes, AI promises tangible benefits to all.

This swimming case study demonstrates how the combination of sensors and AI has the power to raise consumer electronic devices and quality of life to the next level. From wearables, to smart home devices or robots, this synergistic relationship of sensors and AI is here to stay, and its potential is only limited by human inventiveness and imagination.

For any questions or comments, please visit the Bosch Sensortec Community: community.bosch-sensortec.com.

Bosch Sensortec GmbH, a fully owned subsidiary of Robert Bosch GmbH, develops and markets a wide portfolio of microelectromechanical systems (MEMS) sensors and solutions tailored for smartphones, tablets, wearables and hearables, AR/VR devices, drones, robots, smart home and IoT (Internet of Things) applications. The product portfolio includes 3-axis accelerometers, gyroscopes and magnetometers, integrated 6- and 9-axis sensors, smart sensors, barometric pressure sensors, humidity sensors, gas sensors, optical microsystems and comprehensive software. Since its foundation in 2005, Bosch Sensortec has emerged as the MEMS technology leader in the markets it addresses. Bosch has been both a pioneer and a global market leader in the MEMS sensor segment since 1995 and has, to date, sold more than 10 billion MEMS sensors.
For more information, please visit www.bosch-sensortec.com, twitter.com/boschMEMS, community.bosch-sensortec.com

Bosch Sensortec GmbH
Gerhard-Kindler-Strasse 9
72770 Reutlingen
Germany

www.bosch-sensortec.com