



Security through technology

How can air traffic security be improved without bothering passengers with yet more checks? An innovative body scanner shows the way.

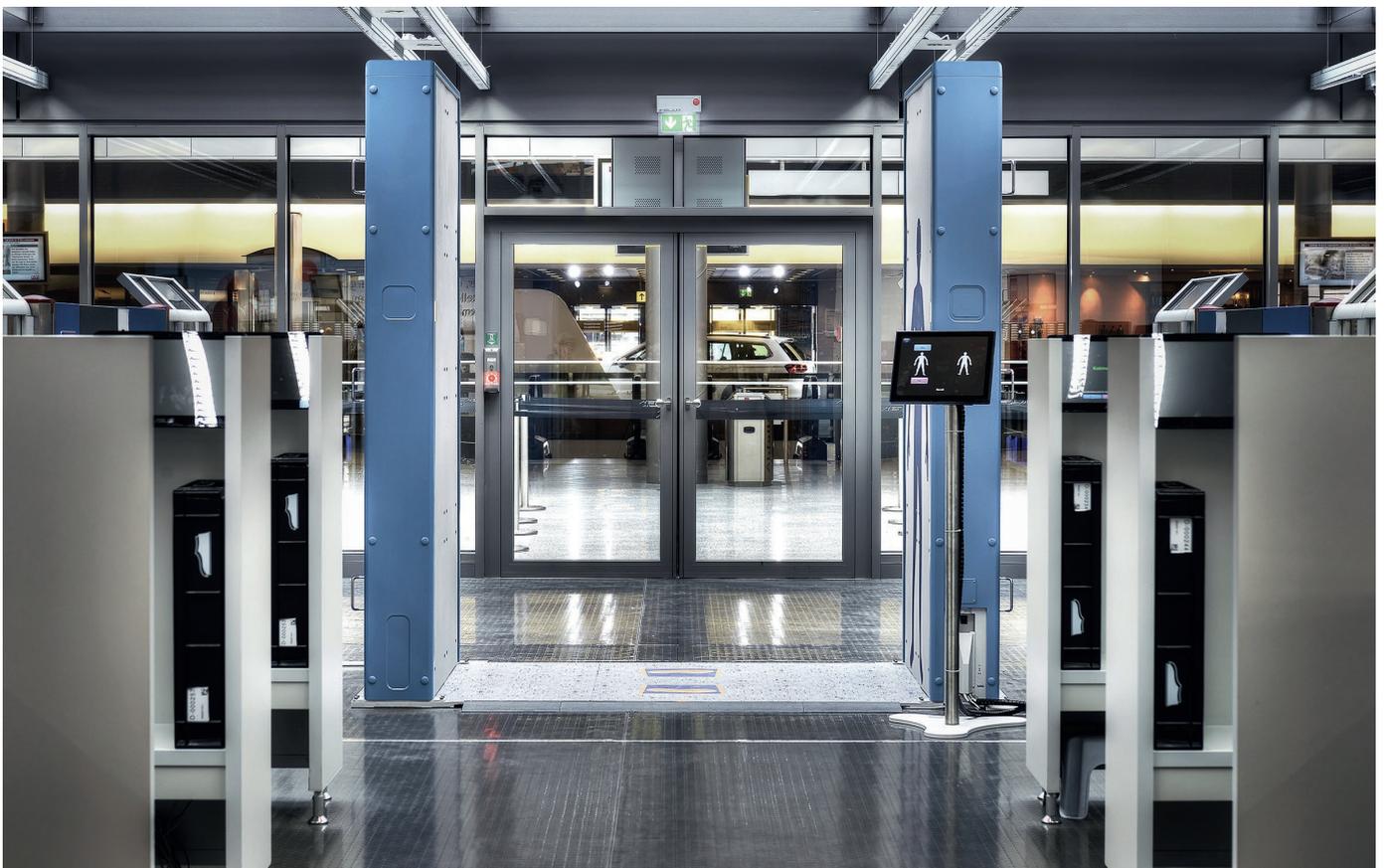
The typical air traveler has conflicting feelings about security. According to a representative survey by the German Federal Association for Information Technology, Telecommunications and New Media (Bitkom), most passengers favor the extensive use of security technology, including body scanners, at airports. At the same time, they are annoyed about a variety of inconveniences, ranging from the restrictions on carry-on luggage and having to take off various items of clothing at the security checks, to the unnatural posture required by conventional body scanners and the pat-downs by security officers. And these are only compounded by the long waits at security checkpoints. Because it is unlikely that security standards will be relaxed any time soon, it is up to technology to find answers to this dilemma in the face of even tighter security.

The goal is to maintain the highest level of security while preserving the greatest degree of convenience possible for passengers. The new R&S®QPS body scanner (Fig. 1) is a significant step in this direction.

A product category takes shape

The first body scanners were developed in the early 1990s, even before an appreciable market for them existed. These backscatter devices operating in the X-ray range were seldom used at airports. These were followed several years later by devices operating in the microwave range, even though demand remained limited. After the dramatic events of 9/11, it became clear that the market for security equipment would

Fig. 1: The R&S®QPS200 scanner with two panels is primarily intended for use at airports. It can be integrated without barriers into virtually any gate architecture. The R&S®QPS100 model (not shown) has only one panel; the test person turns 180° for a complete scan.



develop dynamically. As a result, Rohde&Schwarz very quickly decided in 2007 to become a partner in a consortium working on a project to offer a European alternative to the products from the United States, the pioneers in this category. A three-year research and development phase culminated into a proof of concept that confirmed the consortium's path. However, divergent conceptions of a series production model caused the participating industry partners to forge their own, separate paths. As part of QPASS, the follow-on project initiated by Rohde&Schwarz and funded by the German Federal Ministry of Education and Research, Rohde&Schwarz worked with the Institute of Microwaves and Photonics at the University of Erlangen-Nuremberg, Germany, to develop a pre-production prototype that showed the potential for meeting all expectations, even though new EU requirements would bring additional challenges.

Previously, devices were designed to generate images that could then be evaluated by human screeners. The fact that intimate details were also visible led to an emotionally charged public debate that forced authorities in the US and Europe to change their acceptance regulations. It is now forbidden to display photo-like images at checkpoints. A seemingly simple regulation, but with extremely grave technical consequences. The challenge now was to develop a method of detecting suspicious objects fully automatically. This required that the millimeterwave technology be expanded with a rapid image processing system that could reliably filter out anomalies from the measured data for display on an avatar (Fig. 2). The development team assembled for this task made such rapid progress that a series production model, the R&S®QPS100, was ready for introduction by 2014. Tested under real-life conditions, continually improved, furnished with all applicable certifications and extended to include the

A brief history of airport security checks

The history of airport security, at least as pertains to protection against attacks, is tied to a series of key events and the responses to those events. During the first decades of commercial aviation, airport security was essentially nonexistent since flying was an exclusive adventure limited to wealthy customers and still far from becoming a stage for violent crimes requiring protective measures. Even as hijacking, primarily for political motives, became

prevalent – with an all-time high of 82 hijackings in 1969 – authorities still did not see any need for significant countermeasures. Metal detectors were used on passengers only when there was cause for suspicion. It was not until the 1980s, when the US in particular intensified its war on drugs that passenger checks on the ground were stepped up and sniffer dogs were introduced. The 1988 Lockerbie bombing brought about random luggage scans in Europe; however, it was not until 2003 that a check of every piece of luggage was made mandatory by EU regulation.

In many ways, the 9/11 attacks of 2001 represented the “zero hour” in terms of security policies. At all conceivable levels, authorities did everything possible to prevent repeat attacks, ranging from extensive, cross-border reconciliation of passenger data to the deployment of sky marshals, from prohibiting pointed or sharp objects such as nail files in carry-on luggage to installing armored cockpit doors (installing these doors cost Lufthansa alone more than EUR 30 million, according to the company's statements). Preboarding security checks also saw rapid change from that point on. The attempt by Richard Reid in December 2001 to detonate explosives hidden in the heel of his shoe was thwarted, but the US and a few other countries responded by requiring passengers to take off their shoes for examination. The prohibition against large volumes of liquids came about in 2006 after a plan was uncovered in Great Britain to use liquid chemicals in an attack. During Christmas in 2009, the creativity of attackers extended even to undergarments, when a Nigerian national tried to detonate explosives hidden in his underwear shortly before landing in Detroit (“underwear bomber”). The Transportation Security Administration (TSA), established in the US in response to 9/11, reacted to this attempt by introducing full-body scanners at airports nationwide. Installation of these instruments – which were developed in the 1990s – had already begun in 2007 at airports in the US and else-



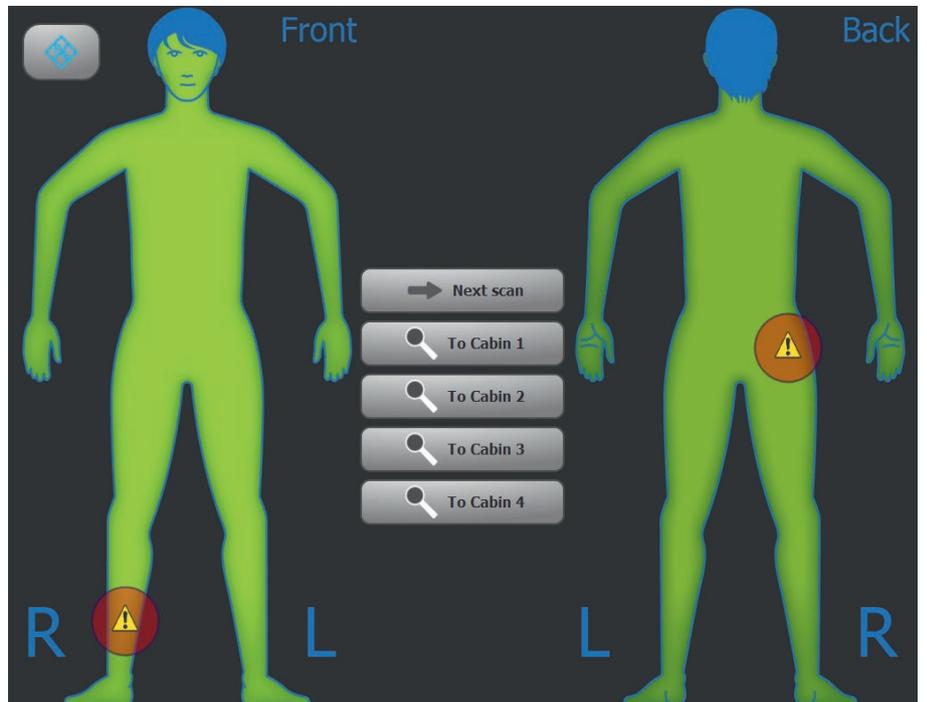


Fig. 2: The scan result is displayed on a neutral graphic (avatar). No personal details are displayed and no personal data is stored.

where, such as Amsterdam, but their widespread use did not start until 2010. This first generation of scanners was based on X-ray technology that made not only potentially dangerous objects visible, but also intimate body details, leading to heavy public criticism. X-rays additionally have an ionizing effect and are therefore damaging to cells, even though authorities ruled out any jeopardy to health due to the low level of radiation from the devices (measurements show that the level is approximately equivalent to what passengers are exposed to during just a few minutes of cosmic radiation). Nevertheless, these backscatter devices have largely disappeared from the market and are now banned in many countries. Even the TSA made an about-face when it removed all first generation devices between the fall of 2012 and May 2013, replacing them with the alternative technology of millimeterwave devices. However, that move was not made out of concerns for public health, but rather because the device manufacturer had not been able to implement a software update on schedule that would depersonalize scan results. In response to the public outcry, US authorities had included a clause in the FAA Modernization and Reform Act of 2012 to the effect that the naked images generated by body scanners should be replaced with a symbolic body graphic identical for all test persons.

Out of health concerns, the European Union banned X-ray scanners (and all technologies using ionizing radiation) in a regulation issued in November 2011. The preservation of personal and data protection rights is also mandatory. Germany conducted its first field trial of a first generation millimeterwave scanner in 2010 at the Hamburg airport. The field tests were carried out and scientifically assisted by the research center of the German Federal Police. 800,000 volunteers, including German Federal Minister of the Interior de Maizière, allowed themselves to be scanned. The objectives of the large-scale trial were to determine how the devices would hold up under real-life

conditions, to uncover any trouble spots, and to find out how to optimally implement common test methods. National authorities work directly with the European Civil Aviation Conference (ECAC), which is responsible for certifications related to air transportation, and the Hamburg trial played a pioneering role here. The test results (which included a high percentage of false alarms) led the German Federal Government to conclude that the devices currently available on the market were not yet suited for general use. Manufacturers have since stepped up efforts to improve reliability.

Latest generation scanners, such as the R&S®QPS from Rohde&Schwarz, are considerably more mature than their predecessors and are suitable for unrestricted, widespread use. Regulatory agencies are also demanding that the scanners speed up security checks rather than slowing them down. The fast devices now available make this possible. The increased use of automated security equipment brings justifiable hope that the perceived burden on passengers will be reduced to a bearable extent in the foreseeable future. A first step in this direction was the EU-wide elimination of the ban on large volumes of liquids in carry-on luggage in 2014 (although limited to medications, special foods, and products obtained from the airport duty-free zone). This was made possible by new technology capable of detecting liquid explosives. Advances in scan technology will soon make it possible to screen through thick layers of clothing, so that passengers will no longer be required to take off their coats and jackets. Solutions are already visible on the horizon that will work behind the scenes, i.e. passengers will be subjected to security checks without even noticing it. The hope is that air travelers will be able to board without challenge, unlike the woman who had her Christmas cake confiscated in Las Vegas because the security guard thought the icing looked a little too much like explosives.

R&S®QPS200 model, the R&S®QPS platform today serves as an innovative security solution not only for airports, but for all environments requiring high-security, restricted access. The demand is high. Countries like Germany are following the example of the US, which began in 2010 to successively outfit all airports with scanners. With the July 2016 signing of a framework agreement between the German Federal Ministry of the Interior and Rohde&Schwarz for the delivery of 300 units, the R&S®QPS200 is on its way to becoming a familiar sight at German airports.

New paths

The R&S®QPS differs from competitive products in how it looks, how it operates and how scans are performed. The tight spaces common with booth solutions are a thing of the past. The visually appealing, space-saving flat panels can be integrated without barriers into the checkpoint area (Fig. 1). The open design gives security personnel an unobstructed view of the entire checkpoint. The scan procedure

– considered to be unpleasant with traditional equipment because passengers are required to hold their hands up in the air as if being stopped by police – is now significantly more comfortable for passengers. Arms are slightly spread in a natural pose that is possible even for physically impaired individuals and is considered to be ethically correct across cultures.

The R&S®QPS is a fully electronic, low-noise solution with no moving parts. It is the only device on the market that relies on the multistatic principle familiar from radar technology, where the reflected transmit signal is applied to a large number of receive antennas simultaneously (Fig. 3). This provides better illumination of the scanned individual, leading to an improved quality of detection.

Aside from a six-monthly calibration check, the system is virtually maintenance-free. These checks are provided on site, of course. Setup and commissioning take under an hour because all time-intensive preliminary work is performed at the plant.



Fig. 3: Multistatic principle of operation: While only one of the 3008 transmitters is active at a time in a panel, all 3008 receiving antennas receive the reflected signal. Since every transmitter also rapidly steps through 128 frequencies before the next one starts transmitting, each scan cycle delivers more than a billion (!) complex values per panel (magnitude and phase), all within only 32 ms.

The technology behind the R&S®QPS

Traditional microwave scanners illuminate objects at frequencies below 30 GHz. In contrast, the R&S®QPS achieves higher spatial resolution as it operates in the millimeterwave frequency band between 70 GHz and 80 GHz, the band also used by vehicle parking sensors. At about 1 mW, the peak transmit power is approximately three orders of magnitude lower than that of cellphone emissions and is almost undetectable in the spot where the scanned person stands.

The scan volume is resolved in finely granulated, 1.9 mm × 1.9 mm × 5.7 mm voxels, which is achieved not only due to the high frequency band, but also through the multi-static operating principle. Implementing this in a high-resolution, close-range scanner was anything but a trivial task. To make a multistatic millimeterwave scanner workable, its surface would have to be fully covered with antennas – which translates into a quarter million antennas per panel for a scanner the size of the R&S®QPS. The effort to reduce the number of antennas to a reasonable level took years of fundamental research and was the basis for more than one doctoral thesis. The result was a structure consisting of 3008 transmitters and 3008 receivers distributed in 32 clusters over each panel in a checkerboard pattern (Fig. 4). In addition to transmitters and receivers, the clusters contain the electronics required for frequency processing and conversion. The receive signals are downconverted to a 25 MHz IF, and the signals from four clusters each are taken to one of a total of eight IF modules located behind them. In the IF modules, they undergo analog-to-digital conversion and are processed into raw “image” data. In a final step, the data is routed via two centralized boards and a PC adapter to an integrated interprocess communications (IPC) module, where final data analysis takes place. Potentially dangerous objects are automatically detected, and their precise location is calculated and displayed. Each panel also houses a synthesis generator for signal generation as well as auxiliary components such as the power supply, signal distribution, interface ports and display elements.

The R&S®QPS200 is designed to perform a full scan in just 32 ms per panel. Computer analysis at present takes several seconds, a time that will be significantly reduced in the future through more powerful data processing technologies. High-performance graphics processing units (GPU) optimized by the graphics cards industry for massively parallel processing introduce new options on the way toward implementing real-time analysis, an essential prerequisite also for future walk-through solutions.

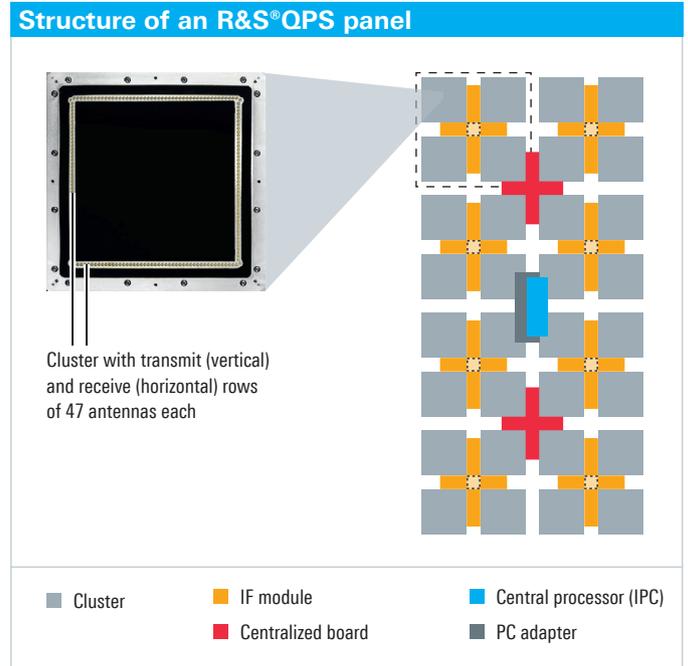


Fig. 4: The R&S®QPS has a modular design. The RF frontend is distributed into 32 clusters in a checkerboard pattern.

The challenge of automated detection

On the surface, a body scanner works much the same as a classic passport photo booth. The person is illuminated, the reflected light is replicated onto a medium (in the case of the scanner to data instead of paper), and the image is developed – by means of scanner software. However, a fully automatic scanner is not intended to generate photographs for human viewing. Instead, its purpose is to deliver an image interpretation, an assessment – which is a significantly more demanding task.

The task is as simple and challenging as this: detect all potentially dangerous objects that are carried on the body or in clothing, regardless of type, size, location and material composition.¹⁾ The all-encompassing scope of this task quickly leads to the conclusion that obtaining a positive validation, i.e. detecting concrete objects by way of comparison against patterns, is predestined to failure. There are simply too many materials and shapes that can be used for firearms or knives, for example. A scanner would have to be capable of recognizing a “thing in itself”, based on its characteristics and purpose, irrespective of shape, material or form – a hopeless endeavor. The goal of the scan, therefore, is not to identify objects but to identify areas on the body that, in the estimation of the analysis software, significantly deviate from the

unsuspicious canonical form. The developers' task thus was to teach the software what is considered unsuspecting. However, any attempt to do this based on a "white list" of harmless combinations is likewise a futile task, and for the same reason as stated above. There are too many possible variations, even with a seemingly easy example such as men's clothing. Is the test person wearing a pullover or a shirt, is it made from wool or synthetics and does it close with zipper or buttons, which in turn might be large or small, made of plastic, metal or mother-of-pearl and placed in a placket down the middle or the side, is there a lanky youth standing in front of the scanner or a burly man of six and a half feet – the scanner must assess all of these and more without error and allow them to pass as normal. It was clear that solving this awkward problem would require a completely new approach, one that brought together methodologies from image processing, machine learning and, most especially, deep learning, a state-of-the-art method for creating artificial intelligence.

Each scan cycle produces a huge data set of amplitude and phase values from the 3D scan volume that can be used as the basis for analysis. The scanner operates in a similar way as a vector network analyzer. Received signals are compared against transmitted signals in amplitude and phase, and the differential value contains all necessary information about the test subject. The challenge lies in interpreting this information

through appropriate modeling, i.e. by mapping the physical data into concrete object characteristics and attributes. Examples of these attributes include signal intensity, surface roughness, and the strength of multiple reflections. In fact, more than a thousand different attributes can be defined and combined into a high-dimensional attribute space. Suspicious objects or materials leave behind characteristic "fingerprints" in this space in that they manifest in specific subsets of attributes (= attribute combinations) in specific ways. Classifiers are used to model these subsets (Fig. 5).

Fig. 6 demonstrates this principle based on a classifier that uses the attributes signal intensity and surface roughness. In this two-dimensional attribute space, an unsuspecting body region can well be distinguished from a region in which, for example, a black powder substitute was concealed under the clothing. Clear decision boundaries are an essential criterion for the usability of a classifier.

At the time that development of the R&S®QPS was started, suitable attributes and classifiers still had to be defined and parameterized manually (feature engineering). During the past few years, however, enormous advances have been made in the area of machine learning, in particular deep learning. The latest version of the R&S®QPS detection software has also been trained using deep learning algorithms.

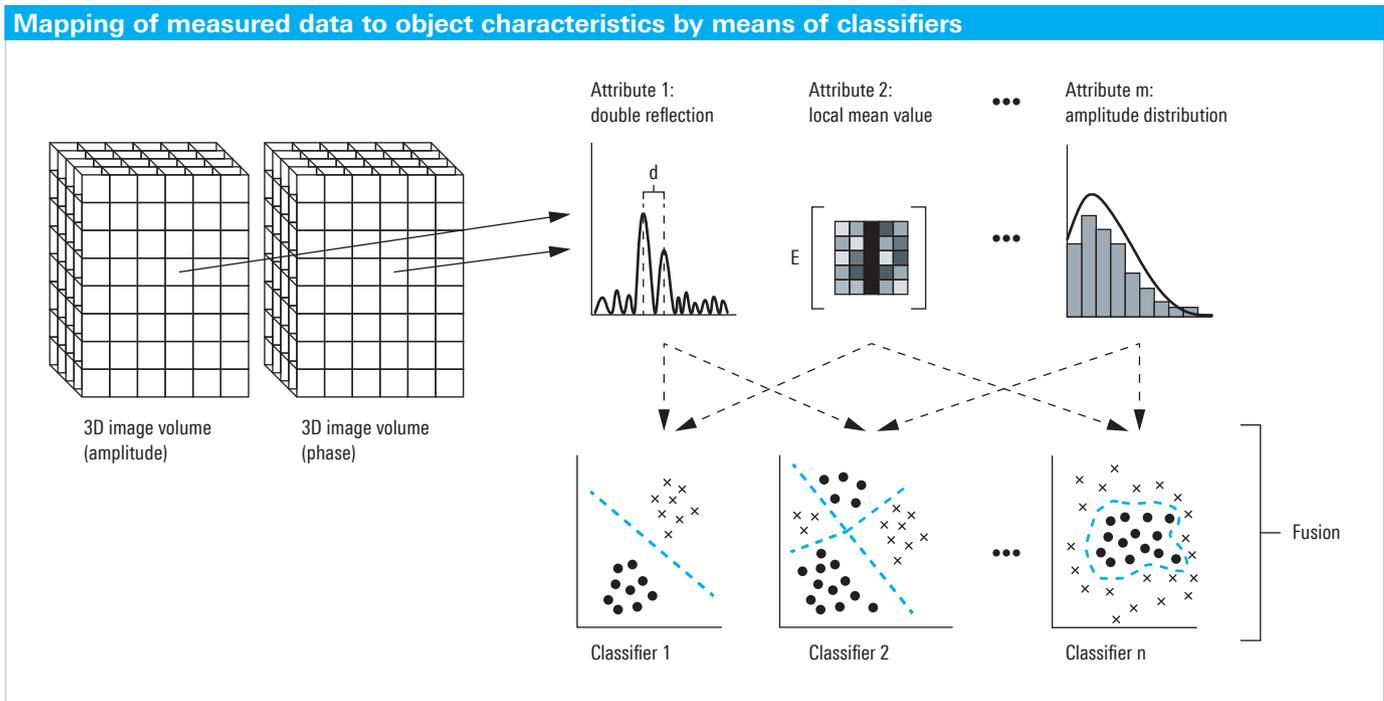


Fig. 5: From the basic physical information (amplitude and phase), attributes are extracted and combined into n-dimensional classifiers, each of which responds to a specific object characteristic or object class. In this example, there are three classifiers, each with two attributes. The superposition (fusion) of all classifiers yields the final detection result.

Deep learning methods have replaced conventional machine learning algorithms in many fields of application. Google's Android voice recognition, Facebook's face recognition and Skype's voice translation are based on deep learning. In early 2016, Google's AlphaGo computer program attracted global attention by defeating multiple worldclass Go players, a feat previously considered impossible. The software's playing strength lay in algorithms and analysis rules generated from neural networks using deep learning.

Neural networks are capable of delivering astonishing results when it comes to pattern recognition. For example, networks especially appropriate for image processing – referred to as convolutional neural networks – now surpass even humans in tasks such as traffic sign recognition. For a neural network to complete a task, its topology and neuron switching functions must be perfectly attuned. The networks behind the R&S[®]QPS software were therefore developed in-house at great effort and expense. To find out whether a network will function as intended, it must first be sufficiently trained with high-quality data²⁾. In this case, the software was fed a large set of labeled training data obtained by scanning many thousand test subjects³⁾. Labels are used to mark any problem zones if existing on a test subject. The type of problem (knife, explosives, etc.) is irrelevant. From the huge number of samples it processes, the software learns on its own what patterns calling for an alarm look like. In an extremely processor-intensive optimization process in which millions of parameters are varied, the deep learning algorithm works its way through the database, finding those attributes and classifiers that are best suited for identifying critical cases. The solution thus obtained is implemented in the R&S[®]QPS firmware. The overall cycle of learning and application is extremely unbalanced in terms of the time required. An extended learning phase (long computational runs on a GPU cluster) produces a program that in actual use can make decisions in seconds.

Deep learning offers crucial advantages in the development of scanner software. This method not only makes it possible to achieve high detection quality, but is also especially attractive because solutions are automatically generated. The software becomes a partner in development, relieving engineers from monotonous routine tasks. Engineers can instead invest their time into perfecting neural networks and deep learning algorithms, leading to even better detection results.

1) Millimeterwave scanners cannot see under the skin, i.e. inside the body, since their waves reflect off the surface – or, more accurately, off the water stored in the skin – one of the reasons for their negligible effect on health.
 2) The networks are trained with prequalified data, so this type of machine learning is also called supervised learning.
 3) These scans are performed under Rohde&Schwarz control at the plant. Data obtained during normal operation at an installation site must never be used.

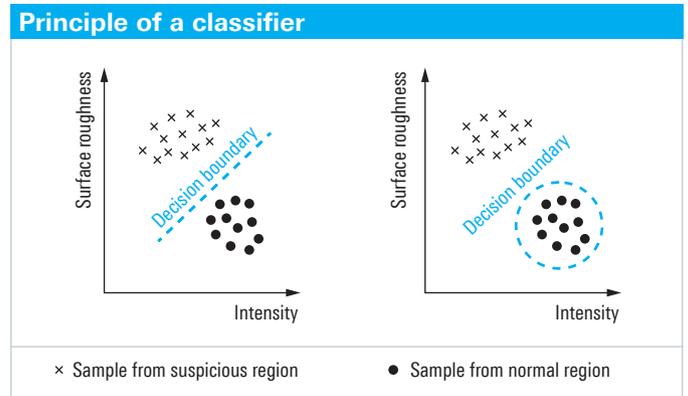


Fig. 6: Example classifier with two attributes for detecting a specific object characteristic. The attributes must be selected so that a clear decision boundary can be defined; two possible boundaries are shown here.

Summary and future developments

With the R&S[®]QPS family of body scanners, Rohde & Schwarz opens a new chapter both for this device category and for flight security. Innovative hardware and software solutions satisfy the requirements of operators responsible for airport security while meeting passenger expectations to the greatest extent possible. Operators can integrate the space-saving devices into the checkpoint area without barriers to ensure high passenger throughput. Passengers experience a comfortable and completely non-discriminatory scan procedure. The technical design of the R&S[®]QPS leaves leeway for developing new models to meet future requirements. In the medium term, rapid progress in the field of massively parallel computing in particular will bring walk-through scanners to the market that will not even be perceived as security equipment and will not impede passenger handling.

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