A TES Electronic Solutions White Paper

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Vital sign detection using 60 GHz radar technology

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Executive Summary

Nowadays, the radar technology finds its way into many different markets. Following the path from bulky military technique it landed in many everyday civilian applications, like medical, automotive, geology or rescue. This was induced by emerging developments in integrated circuit design and overall system miniaturization. Ability for operation at higher frequencies is growing with development of integrated circuits in the gigahertz frequency range, enabling at the same time, the reduction of the system size.

New, formerly non-allocated high frequency bands became popular for various applications. TES Electronic Solutions GmbH is using its unique position as a specialist in RF system design and signal processing systems to address this exciting field of applications with a simple radar-based vital sign detection system, operating in the worldwide non-licensed 60 GHz ISM frequency band.

The sensor is based on Doppler radar capable of operation in 59 - 64 GHz frequency band. It is characterized with compact design due to small antenna size and integrated front-end part. The real-time data data-acquisition acquisition system enables low-latency detection, measurements and tracking of breathing and heart beat of the living subject. The same system is usable for efficient movement and intruder detection and can be integrated into a larger sensor network. Such sensors are usable as efficient solution in many applications, presently solved by wired, bulky and/or costly parts.

The automotive market is growing up rapidly today and the penetration of the electronic systems in it is growing even more. Increased number of vehicles on the road, higher speeds, an ageing population, they all are increasing the potential for accidents due to driver's health problems. The integrated radar sensors are ideal solutions for improving safety by early detection of potential driver health hazard.

Detection of human vital signs inside of the vehicle can become a part of the modern driver assist and safety systems. Consisting of one or more Doppler radar units, with a possibility to cover all vehicle seats, it can be essential in the case of sudden driver's health or in detecting the left-behind child, if it is forgotten in a closed car. The same hardware can also detect an intruder's presence and be integrated in a car steal protection system.

In medicine and sports, there is also a plethora of possible applications for such systems. In some cases, Instead of traditionally electrocardiography (ECG) measurements of heart activities with a lot of wires connected to the body, a contact-free human vital signs detector brings more comfort for the patients. It cannot replace the ECG in clinical investigations, but can be usable for observing chronically ill patients or sportsman during their activity.

Some medical observation has to be done over the people during their physical activities. Some other people want to make their training more effective and it is possible only through their vital signs monitoring during the training. For both groups the non-contact heart activities measurements are more comfortable.

Doppler radar inclusion into home healthcare systems enhances the quality of patient's life, especially for senior people and people with limited mobility. With these contact-free detectors the monitoring of vital signs is allowed all the time, and the results of measurements can be electronically sent to a medical institution.

This kind of non-contact monitoring of baby's vital signs all the time allows parents to overcome the critical period of possible sudden infant death syndrome more easily and to be able to react fast, if it is a necessary.

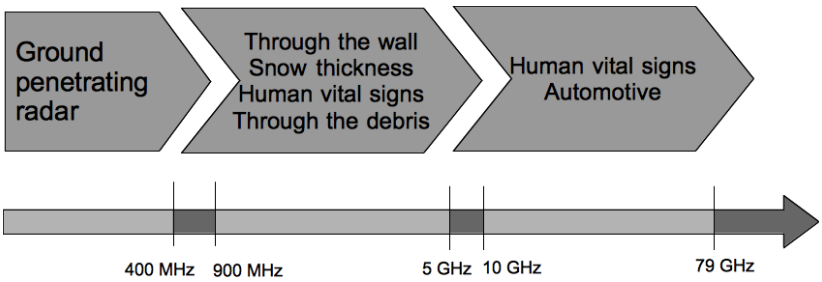
The vital signs monitoring without wiring is especially suitable for the animals' observation and in veterinarian applications. The vital signs of animals can be measured without their sensing of that.

The tests provided on the demonstrator system proofed its applicability on human subjects in different scenarios, including the movement and various clothing and environmental conditions.

Requirements

Since the radar technology was introduced during the World War II, it has quickly found the way from strictly military to many civilian applications. Some types of radars emerged into medical, automotive, geology, rescue and many other markets. The radar development has significantly expanded after integrated circuits had reached operating frequency in the gigahertz range with cheap and powerful computational cores.

In general, radar operates sending a signal into the medium, listens to the target's echo and then based on transmitted and received signal calculates the target's parameters. Depending on the medium and target, different operating frequencies are more suitable for various applications.



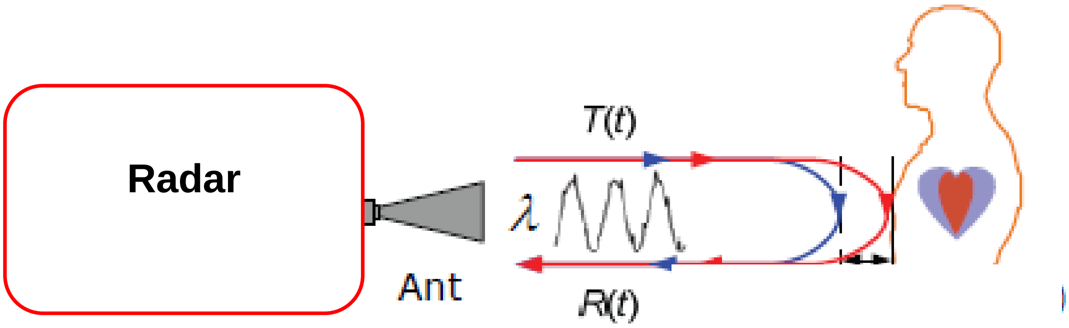
Lower operating frequency band is more suitable for ground penetrating radars (GPR). They achieved bigger penetration depth as on higher-frequency bands. The GPR is mostly using for mine detection and archeological scanning.

Frequency range of a few gigahertz is suitable for through the wall imaging, by using ultra wideband technology (UWB). These radars are used in emergency hostage situations as well as in rescue missions. They have to locate human subjects buried under earthquake rubble or hidden behind various barriers. Radars operating in this frequency range can also be used for detecting vital signs (heartbeat and breathing), where human can be on a hospital bed, doing sport exercise, being covered under snow (avalanche accidents) etc. The unclear regulatory issues in this frequency range, together with very low allowed transmission power, and rather bulky antennas limit the wide applicability of such systems in everyday applications.

To overcome above listed limitations, the usage of systems in the millimeter-wave range (above 30 GHz) offers a number of advantages. The relatively large worldwide available bandwidth in the 60 GHz frequency band for ISM (industrial, scientific and medical) applications enables implementation of novel applications and standards, including the vital sign monitoring systems. Additionally, in 77 GHz millimeter wave frequency range are allocated the established automotive radar applications for various long and middle-range radars. The inclusion of radar sensors in automatic cruise control and safety applications is become standard for most middle class cars nowadays.

The radar application for human vital sign detection has been introduced in late 1970s, but no serious and more intensive researches have been conducted until year 2000. Basic principle for this detection is Doppler (CW – continues wave) radar, as illustrated on Fig. N3. The transmitted wave is reflected from chest and the body movements induced by the heartbeats and breathing to modulate the incident wave. The reflected wave is now carrying the information about human vitals.

Implementing vital sign detection radar in the millimeter-wave frequency range enables compact design due to small antenna size, which still can have a considerably high gain. Recent advances in semiconductor technology provide a possibility to integrate the radio front-ends as well. The biological effects of the exposure to radio waves are also lower in this frequency range, since the skin penetration depth on 60 GHz is a way below one millimeter, so very low amount of the energy is absorbed in the human tissue. The drawback of having higher transmission losses in space and hence, less measurement range, are by far compensated by above-mentioned advantages.



Having to go the same way the standard automotive long range radar systems did before wide deployment, the radar system for vital sign detection still needs to take some hurdles:

- The device needs to be designed so that the integration in the typical application environment can be facilitated. It is to be flexibly implemented in different user scenarios, so that small size and compact design are necessity.
- The performance needs to satisfy the application standards which are met also by wired devices for the same applications.
- The usage and maintenance of the device need to be as simple and user friendly.
- The overall production and deployment price of the system needs to be competitive compared to the existing systems in use for targeted applications.

Application scenarios and markets

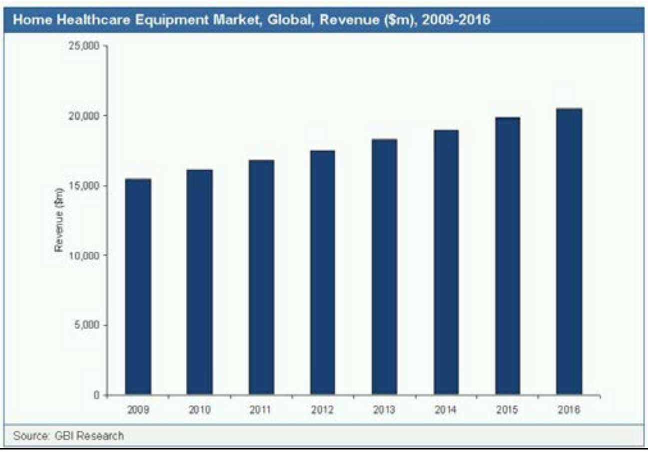
Healthcare Applications

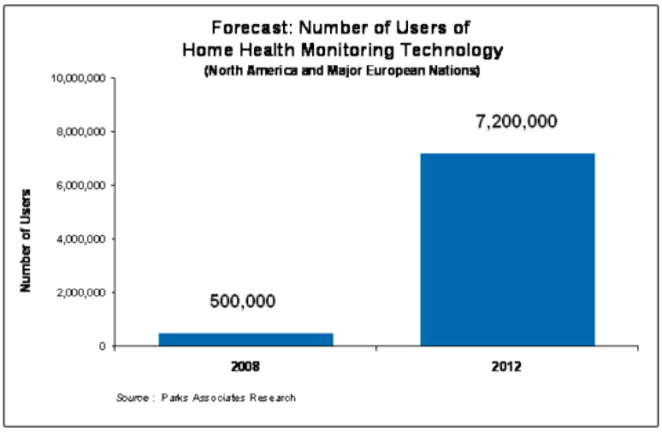
Traditionally, electrocardiography (ECG) records, through the electrodes attached to the specific anatomical position, not only heartbeat signs but complete electrical activity of the heart. The first usage of ECG dates back 80 years and is still expanding to the new markets. According to the market research[1], it is expected that ECG telemetry reach more than billion dollars by 2015. Factors driving market growth include increasing cases of cardiovascular diseases and ageing population. These facts induce growth in the number of people receiving home care, and it is expected that home healthcare shall cause a significant amount of the forecast market growth.

Home healthcare system enhances the quality of patient's life, especially for senior people. Monitoring their vital signs at their homes can help them to live more independently. It is even possible, through the connections of these systems into smart home networks to conduct a professional patient monitoring. Home healthcare and patient monitoring become more and more attractive – in 2012 it was expected to be 15 times more users of home care than in 2008.

Under permanent monitoring, there are circumstances when a person can feel very uncomfortable and obstructed being attached to too many wires/electrodes. This network of wires reduces patient's mobility and adds one more difficulty that needs to be overcome by the patient. Contact-free detection can overcome these obstacles, because monitoring of vital signs is done without using any electrodes or sensors touching the body of the subject. These non-contact detectors (radar) that monitor human vitals (heartbeat and breathing) can be mounted over the bed, wheel chair, or any other places close to the patient so more comfortable space is given to patients for daily routines. Therefore, the radar vital sign monitoring can be used successfully in the healthcare application in a clinical or home environment.

Of course, such applications are not just limited to the healthcare, but can also be expanded to veterinarian applications and animal observation.





[1] Global Strategic Business Report, Jan 2011

Infant Vital Signs Monitoring

Sudden infant death syndrome (SIDS) is marked by sudden death of an infant that is unexpected and remains unexplained. Statistics[2] show that SIDS is third of 10 causes for infant mortality and in Western World is still around 0.5 deaths per 1000 live births, taking more than 2500 babies each year just in the US. An infant is at the highest risk for SIDS during sleep and permanent monitoring of baby's vitals during the night could prevent and reduce the risk. Nowadays, there are some baby monitors that are equipped with motion sensors and if baby doesn't move within a predefined period of time, it activates vibration to stimulate infant's breathing. Unfortunately, many of these monitors are large, complicated to set up and have electrical cables or straps which babies may get tangled in.

Non-contact monitoring of baby's vitals solves abovementioned obstacles. The device could help parents to overcome the critical period more easily and be able to react fast, if necessary. The monitor unit is designed to hang over the infant's crib and can communicate wirelessly with the receiver unit, allowing a parent to monitor the child remotely.

Vital Signs Monitoring in a Vehicle

Safety is one of the most important issues in the automotive market today. More vehicles on the road and higher speeds increase the potential for accidents. In Europe, each year about 1.2 million accidents causes more than 40 000 deaths. Human error is involved in 90% of all accidents[3]. These numbers force automotive industry to find and investigate solutions that could improve statistics. One of the suitable solutions is a driver assist system. These modern systems are based on the radar technology, and most popular of them are pre-crash sensing and collision warning systems. Much faster reaction time than drivers brings these radars on the top of devices that could reduce the human error. It is estimated that radars could prevent more than 20% of collisions [4].

The sudden driver's health problems (heart attack, sleep due to prescript drugs or fatigue…) can cause the accident too, and although it is not a major accident cause at the time (less than 6%), it can become more and more important with ageing population and increase of the number of elderly drivers. Permanent non-contact monitoring of driver's vital signs can activate the car safety system and issue an emergency call or even take the control over the further tour.

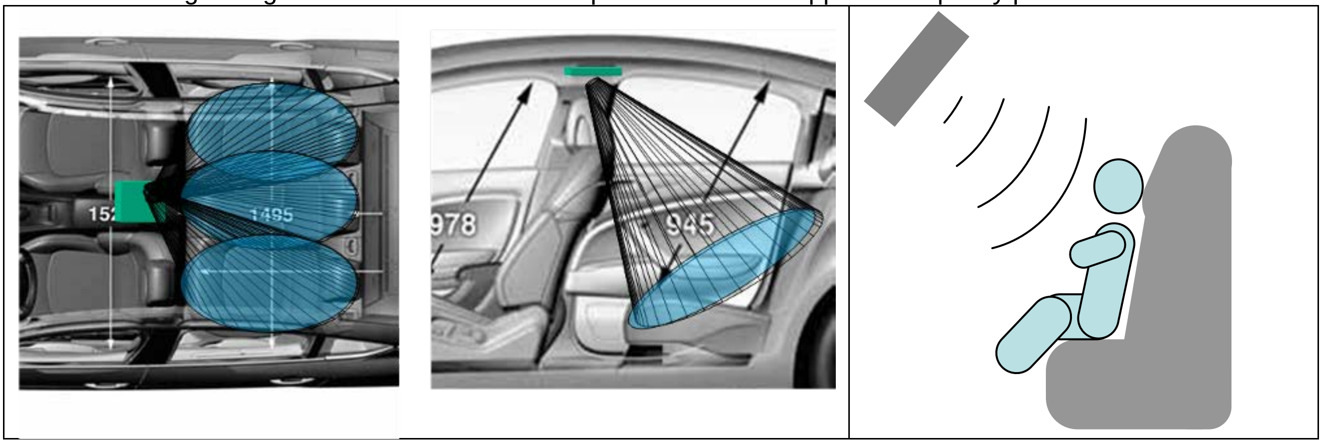
A left-behind child inside of the locked car can become a victim of hyperthermia under sunny weather conditions. Each year in US more than 40 children dies left in a car[5]. The vital signs monitoring inside the vehicle can solve this problem. With the same hardware, the burglar alarm can be implemented, which can be activated in the presence of vital signs or detected movement in the cabin. Additionally, by monitoring of vital signs on all cars seats their occupancy status can be generated activated appropriate seat belt reminder and airbags control function.

Name of the application	Application type	Application Purpose	Position
Child Detection or Burglar Alarm	In the parked position	Detection of a left-behind child inside the vehicle, or detection of an intruder	All seats
Driver monitoring	During the driving	Monitor the heart and breathing frequency of the vehicle driver	Driver seat
Seat Belt Reminder Function and Airbags Control	During the driving	Monitor the occupancy status of all seats	All seats

[2] Vital Statistics of the United States, NCHS, 2004
[3] eSafety - Improving road safety using information and communication tech, 2007
[4] Development status of next generation automotive radar in Eu, 2009
[5] Hyperthermia Deaths of Children in Vehicles, 2012

Interior radar mounting position can be chosen depending on the application scenario. The reasonable assumption is that in all application scenarios, the relative position of the passenger respective of the radar position can be known. Usually the passenger sits regularly on the seat with the fixed position, and the distance variations due to the seat adjustment position can be neglected as the uncertainty factor. Therefore, the zone where possibly the vital functions can be registered is relatively easy to determine for each seat and sensor position. Consequently, the antenna radiation patterns can be designed so to cover mostly these areas and reduce the influence of the clutter from surrounding surfaces.

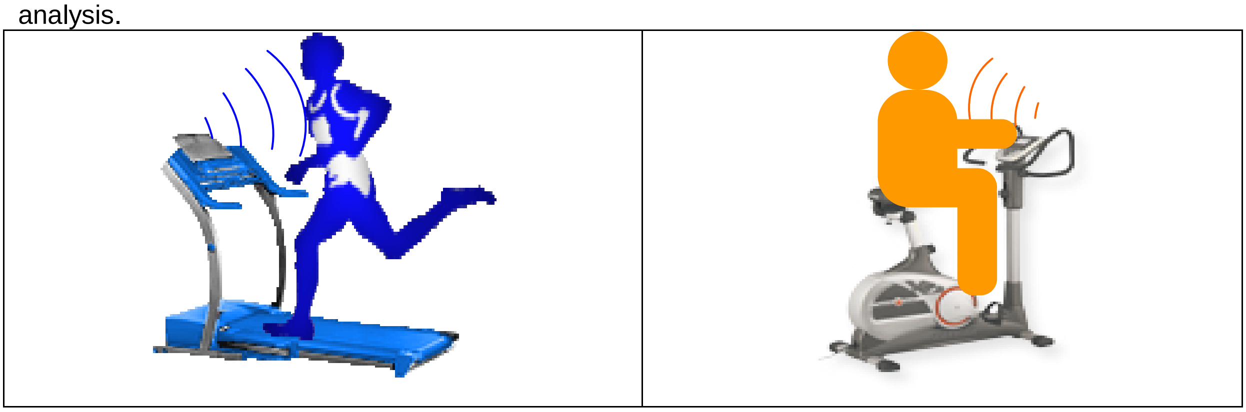
Of course, the areas of interest can be shaped according to the application scenario and can be different for a driver seat from those at rear seats, where also a cradle with a baby can be placed. At figure bellow an illustration is given for the application covering the three rear seats with three individual beams from a single box, placed in the car ceiling. The adjusted radiation patterns for the beams can be implemented using the appropriate architectures. However, the most straightforward way is to use three antenna arrays with suitable radiation patterns and a three-channel transceiver. Alternative approach of successive switching all three antennas using a single transceiver needs to be proofed from the application quality point of view.



Vital Signs Monitoring During Sport Activities

There are two main groups of exercisers that should monitor their vital signs, especially heart rate, during the physical activity. First group are exercisers which need to stay in a specific heart rate zone due to the medical recommendation (rehab patients), and second group are competitive athletes who use the data for effective training. There is also a third group of people that do amateur exercise. In US more than 16% of people do exercise on a daily basis and 55% of them do it alone. Top three workout activities for them are walking, weightlifting and workout using cardiovascular equipment[6]. For all abovementioned groups of users, treadmill and ergo-meter are widely used during these exercises. In order to measure heartbeat, exercisers have to attach a finger/ear pulse meter, a chest strap or similar device. These metering devices have cables and are unsuitable for exercise, because they very often detach from the body, or cause inconvenience during the use.

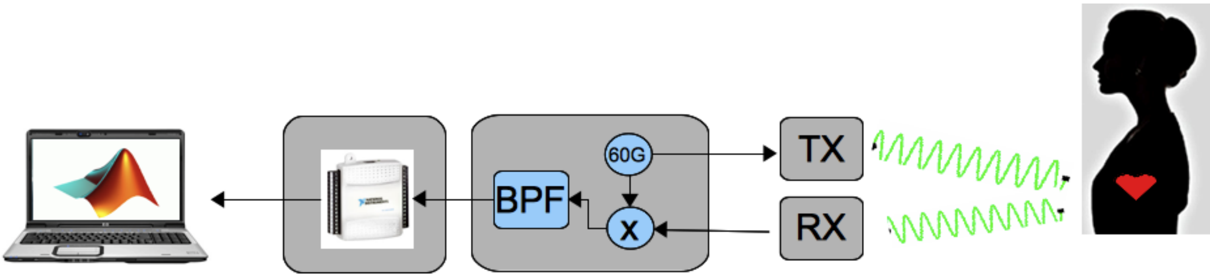
Non-contact metering device fills the gap and allows the exerciser to focus only on training. Their vitals can be monitored and demonstrated in the table in front of the sportsman and logged on the memory for later analysis.



[6] US Department of Labor, Spotlight on Statistics, 2008

Radar Solution

The implementation has to be compact-size and driven by the need to obtain fast and effective mean of showing the feasibility of some of the application scenarios of interests, especially human vital sign measurements. In order to achieve it, the demonstrator architecture is kept as simple and as modular as possible.



Modular architecture consists of antennas, RF hardware, acquisition card and PC. Demonstrator is operating at 60 GHz, and therefore, its antennas are very small, allowing the better integration into a small-size package. RF hardware is well shielded so the electromagnetic radiation is not affecting other devices operating in close spectrum range.

Acquisition card is used for fast and accurate data acquisition. Together with signal processing that is done in PC, a full real time calculation is achieved. Signal processing is implemented in Matlab. It is based on a self-developed intensive adaptive filtering algorithm, adopted for human vital sign monitoring. Real time calculations in the algorithm minimize measurement latency and increase the measurements accuracy.

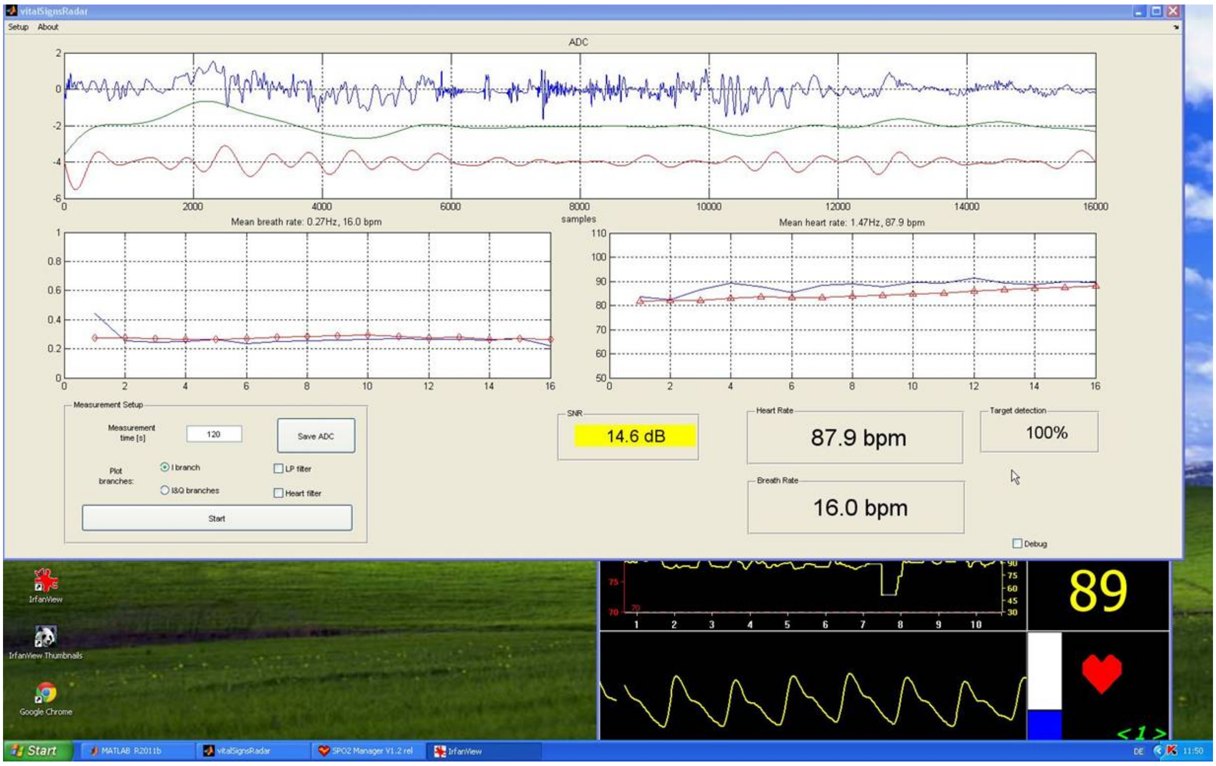
Software measures human heartbeat and breathing, plots the results together with reference values from pulse meter. Reference heart rate is measured with portable a pulse meter oxi-meter. Measurements of vital signs were shown great matching to those measured with pulse meter.

All measurements have been done in controlled laboratory environment, which means that only one adult person, frontal faced to the radar, was radiated with radar beam at the time at one-meter distance, and that person was sitting still avoiding random movements as much as possible.

Measurements of vital sign show good accuracy even at greater distance. The system is sensitive enough to detect a person at three meters distance. This could be very useful in scenarios where only one beam has to be used for scanning more than one person. So, without any enhancement, this demonstrator can be implemented for different application scenarios.

Measurement setup in the lab

The illustration of prototype measurement system presentation is given on the screenshot on the figure bellow. The developed GUI enables both tracking of the acquired analogue signal as well as the observation of the breathing and heart beat signal content. Average and instantaneous estimations of the breathing and pulse rate are tracked on the separate graphs, together with signal to noise ratio estimation and numerical values of the parameters. For comparison, a window containing reference measurement data from the pulse-oximeter is shown in the lower-right corner of the screenshot.



Radar GUI and pulse-oximeter measurements

This radar demonstrator has completely proofed the concept of non-contact metering of human vitals, by maximal exploiting the properties of millimeter-wave frequencies and adaptive signal processing techniques. Unambiguously, this new radar technology could be used for remote metering and additional investigation in this field is justified because this market has great potential especially in the near future.

Conclusion

TES Electronic Solutions is a provider of a wireless sensor for the vital sign detection operating in 60 GHz ISM frequency band. It is intended for use in automotive, medical, safety or rescue applications, involving human subjects. The adaptation for veterinarian applications is straightforward with minor adaptations in signal processing algorithmic part and can be done according to the characteristics of the animal species that are to be involved in the observation.

The developed sensor hardware and software enables monitoring of the breathing and pulse rates in real time with controllable signal acquisition and measurement parameters. The measured results have been matched to reference measurements provided by a portable pulse-oximeter device. The future developments include expansion of the algorithmic capabilities and further integration and miniaturization toward the product implementation.

The radar based sensor is most suitable for driver monitoring, infant detection or cabin supervision applications in automotive environment. Alternatively, it can be easily used for the long-term patient observation in home environment or for the athlete monitoring during the training process. The detection of life signs, without touching or moving severely injured persons in crash accidents, can be one of possible future applications for such sensors.

These and many more applications are in line to be fulfilled with future developments and integration of the TES wireless sensor programme.