FEATureFACE – AN INNOVATIVE COLLISION AVOIDANCE SYSTEM FOR THE UNDERGROUND MINING INDUSTRY

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ABSTRACT
According to Mine Safety and Health Administration (MSHA) in the United States approximately 22% of all mining related fatalities occurred due to visibility issues in coal mines. In European coal mining both, longwall operations and mobile mining equipment such as road headers, side dump loaders and drill jumbos are used. Therefore, a universal system to prevent accidents and collisions is highly required. In the EU funded project FEATureFACE, an innovative collision avoidance system for underground mining environments has been conceptualized and is currently being implemented. A consortium of multiple academic and industrial partners, including machine manufacturers, sensor manufacturers, mine operators and academic institutes, has been established, allowing the creation of a modern collision avoidance system which incorporates the needs of the industry today. The usage of multiple versatile technologies (electro-magnetic and sound-based time of flight, signal strength measurements and both, active and passive radar technology), their intelligent integration and fusion allows the localization of both miners and static objects (e.g. walls) with high accuracy and reliability. In this paper, the basic concept is described as well as results of first field measurements.
**INTRODUCTION AND FEATuR FACE CONCEPT**

In underground mining visibility of moving machinery is often limited by environmental conditions such as darkness, dust and viewing angle. Therefore, nearly one quarter of all mining-related fatalities are being referred to visibility issues. To improve safety in underground mines operators increasingly apply collision avoidance systems (CAS). The main objective of such CAS is to prevent accidents and collisions of moving machinery with people, vehicles and other mobile equipment. In the FEATuR FACE project an innovative CAS is being developed by integrating multiple technologies into one system resulting in the creation of a diverse redundant collision avoidance system using the individual advantages of each of the technologies.

To identify the main requirements for CAS, current safety conditions in underground coal mines were analyzed and user surveys were carried out to identify potential risk factors. As a result, the following key requirements were determined:

- Sensors have to be placed on the moving machine and not at fixed locations in the mine.
- In order to localize present personnel, usage of tags with range of up to 20 m and an accuracy of 0.1 m is required.
- Detection of vehicles and passive obstacles should be carried out in close vicinity to the machine contour (2 m distance).
- The proximity area around the machine is divided into zones (critical zone, warning zone, caution zone, safe zone), enabling the system to react when personnel enters certain zones.

Moreover, the CAS system has to deal with harsh environmental conditions and disruptions caused by metalliferous surroundings. A flexible technology, which is transferable to other machine types is being demanded.

These requirements are addressed by FEATuR FACE with its unique concept. Through the usage of multiple technologies FEATuR FACE combines their strengths and thus compensates their individual disadvantages. In the course of the project different detecting technologies for local positioning in underground mines were analyzed regarding their conformity with the identified requirements. As a result, the following technologies deemed as feasible for the use in the FEATuR FACE system:

- UHF RFID\(^1\) technology, low frequency electromagnetic field technology, radar ranging with radar based return time-of-flight (RTOF) measurement principle
- Sound-based localization
- 2D imaging radar technology including active radar

The first system, applied UHF RFID technology, enables long range positioning and communication (up to 100 m), whilst low frequency electromagnetic fields provide a reliable detection of vehicles and personnel in near field up to 10 m around the moving machine (Schmidt und Könemann 2007). Radar ranging with RTOF measurement promises high accuracy at medium range distances (Becker 2013). The second system, a newly developed sound-based localization system using RTOF measurement, provides very high accuracy for position measurement at medium range distances (Hammer 2014). Finally, the third system based on 2D

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\(^1\) Ultra-High-Frequency Radio Frequency Identification
imaging radar technology is used for the geometric detection of the environment and untagged objects (for example rocks and ribs) in short and long range distance as well as for detecting semi-active tags worn by personnel.

The intelligent integration and fusion of the above mentioned technologies enables the envisaged system to localize mining personnel as well as static objects with high accuracy and reliability. The combination of redundant information from several detectors and adaptive signal processing together with algorithms for sensor and data fusion facilitates secure detection of the environment with a reduced false alarm rate, thus improving safety and productivity.

This paper describes the different subsystems and used technologies in further detail. Furthermore, the performed field tests and their results are presented and discussed. Finally, the future steps to be taken in the project are presented.

SENSOR SUBSYSTEMS

EM-BASED LOCALIZATION

To enable the detection and localization of personnel based on electromagnetic principles, the system employs several technologies to achieve the localization of tags in the vicinity of the machine.

The tags are identified and recognized by the system through an RFID channel. For this purpose, an RFID antenna is mounted on top of the machine (see Figure 1), making it possible to recognize tags in a radius of up to 100 m. While the RFID technology on the one hand lacks accuracy and robustness for positioning needs, it on the other hand offers a relatively cheap way of communication and identification. To facilitate an omni-directional detection of tags, the antennae’s design was optimized for an anisotropic radiation pattern (see Figure 2).

Figure 1: RFID antenna (base station).

Figure 2: Radiation pattern of RFID antenna (base station).

Once a tag has been detected by the RFID channel, two more technologies are utilized to gather more precise positioning information: A radar-based RTOF and a received-signal-strength (RSS) system.

The radar-based RTOF systems can be used for real-time localization. The technology was tested under mining conditions several occasions. The RTOF system applied on this project utilizes the 2.45 GHz SHF band and measures the return time-of-flight between the base station and a mobile tag. Thus, through knowledge of the speed of light, the distance between base station and
mobile tag can be calculated using Eq. (1). \( t \) represents the return time-of-flight, \( c \) the speed of light and \( d \) the distance.

\[
d = c \cdot \frac{t}{2} \tag{1}
\]

Furthermore, the system employs several advanced signal processing techniques, which allow for offset correction and clock drift calibration.

To support the radar-based RTOF system, the system utilizes oscillating magnetic fields to localize tags. The main advantage the magnetic RSS has over the radar-based RTOF evaluation is the magnetic fields being fairly uniform even in the presence of large metallic constructions. This is of major importance for mining applications to be able to ensure reliable and consistent localization in the close vicinity of the machine, where the danger for mining personnel is the greatest. A rectangular antenna (see Figure 3) is furthermore being used to facilitate the best performance of the system.

![Frame antenna for the magnetic RSS system (base station).](image)

The magnetic field emanated from the antenna was analyzed in extensive laboratory and field tests, leading to the exact calibration of the system. Exemplary measurements of the measured field strength in different distances are shown in Figure 4.
While the aforementioned base stations all are applied to the machine, the tags need to be worn by miners. All necessary EM sensors (RFID, radar and magnetic field) were integrated into one small tag (see Figure 5). This tag is optimized for low-power operations and draws its energy from the battery of the miner’s cap lamp. The tag facilitates all necessary operations to communicate and localize the tag relative to the base station on the machine. A processing unit on the tag performs all necessary tasks. This includes the communication via the UHF RFID channel, the RTOF measurement for the radar system and the field strength measurements for the magnetic field.

![Figure 5: Tag for EM-based localization systems.](image)

**SOUND-BASED LOCALIZATION SYSTEM**

The simplified principle of the sound-based localization system (SBLS (Hammer, et al. 2015)) is depicted in Figure 6. It mainly consists of a base station mounted on the mobile mining machine and multiple mobile tags carried by personnel and other vehicles. As a response to a trigger signal the acoustic measurement signals are emitted and recorded by mobile tags. By correlating the recorded signals with the original reference signals the distance can be calculated. In the paragraph below, this process is described more detailed.
Acoustic position estimation is based on the time-of-flight (TOF) measurement of audible sound signals. For this purpose six ATEX-certified loudspeakers were mounted on both sides of the mobile machine to emit acoustic signals, whereby each loudspeaker itself emits an individual signal to provide a possibility for identification.

The emitted acoustic signals are recorded simultaneously by three microphones arranged in a triangle (120°) on the safety helmet of the personnel. To mark the beginning of a measurement, a radio frequency (RF) module transmits a trigger signal simultaneously to the acoustic signal. Personnel and vehicles, respectively, carry mobile tags which receive the trigger signal and measure the signals’ time-of-flight $t_{TOF}$. This time is the absolute time that it takes for a signal from emission to reception. With the additional knowledge of the speed of sound ($v_0 \sim 346 \text{ m/s}$ at a temperature of 24 °C) the distance between the tag and each loudspeaker can be calculated. By measuring multiple distances from different loudspeaker locations the position of a person can be estimated. Consequently, the distance can be estimated with Eq. 2, where $v_0$ is the speed of sound and $t_{TOF}$ is the time-of-flight. (Hammer 2014)

$$d_p = t_{TOF} \cdot v_0$$

As the speed of sound depends on the ambient temperature the temperature is measured by a sensor on the machine. Knowing the actual temperature the following approximation (Eq. 3) can be used, with $T$ representing the actual ambient temperature in K: (Hammer 2014)

$$v_0 = 331.5 \frac{m}{s} + 0.6 \cdot (T - 273.15 K) \cdot \frac{m}{s K}$$

In order to differentiate signals from background noise and to identify the individual signals from each loudspeaker, the correlations between the received acoustic signals and the reference signals are calculated on the mobile tags. Furthermore a peak-picking algorithm helps
distinguishing potential reflections from the line-of-sight measurement signals. Against this a backdrop, the DSP\textsuperscript{2} board computes different TOFs on each mobile tag.

At first, a linear frequency modulated (LFM) signal was considered for the acoustic signal. While this works well for stationary tags providing robustness against potential background noise, a movement of the tag diminishes the localization performance dramatically. (Hammer 2014)

Once the tag is moving a frequency shift arises due to the Doppler-Effect leading to signal distortions and, hence, to poor performance of the estimations of the distance and the position. As to employ a Doppler-tolerant signal, hyperbolic frequency modulated (HFM) signals are used which exhibit optimum correlation performance at constant velocities. The compensation of the Doppler-shift is then obtained through the usage of HFM chirp pairs (Hammer 2014).

Mobile tags send their individual results to the base station on the moving machine via RF transmission. The base station contains an industrial PC running Matlab to estimate the mobile tags positions based on bilateration and to start and stop the measurements. (Hammer, et al. 2015)

**2D PASSIVE IMAGING RADAR & 2D ACTIVE TRANSPONDER RADAR-TECHNOLOGY**

In harsh environments radar technology has been proven to be a robust technology fulfilling extended availability requirements. In dirty, dusty and foggy environments, where optical systems cannot be used anymore, radar still provides reliable distance and speed measurements.

Two different radar types were evaluated, taking into account different aspects of a CAS system.

- **iDRR**: 2D passive imaging radar with two different modes: narrow field high range or wide field medium range.
- **iSWR**: 2D active reflector with wide vertical and horizontal sector, medium range

The 2D imaging radar types can be used to measure distances along a plane with an opening angle of about 50°. The elevation angle of the 2D imaging radar depends on the distance of the measured target with about 1° in close range and about 2° in far range. Multiple sensors of this type can be used together being distributed around a mining vehicle to detect walls and other obstacles around. Thus collision avoidance systems and other supporting applications can be realized with this type of sensor.

Compared to the passive imaging radar the active reflector radar working with switched reflectors is only able to detect active tags. Using a center frequency of 5.8 GHz, the elevation angle grows far larger, thus enabling the detection of tags that are even partly hidden or lying on the ground next to the machine. This increases the availability and reliability of any CAS system since, e.g., persons next to a machine still can be detected.

**2D passive imaging radar**

The iDRR (Figure 7) is a 77 GHz radar with a range of up to 100 m and an angular view of up to 50°. The transmit and receive channels are operating simultaneously and share the same antenna. The achievable range and the surface reflection angle is depend on various aspects of

\textsuperscript{2} Digital Signal Processing
the reflecting material, like particle size, water content, metallic surfaces, density and measurement angle.

Using the iDRR sensor it is possible to detect surfaces, displayed like in Figure 8. The image shows a rectangular grid with squares that represent 1m in length. The shown surface is about 12 m away from the sensor. Different radar intensities are shown in different grey scales.

**Figure 7: Scanning imaging radar – iDRR.**

**Figure 8: Visible surface in the radar image.**

**Active reflector radar**

With the Switched Reflector Radar iSWR (see Figure 9) detection of modulated switched reflector tags on a 2D plane with 120° (±60°) angular measurement and an orthogonal detection angle of 30° (±15°) is possible.

**Figure 9: iSWR radar unit.**

Besides the direction/angle measurement, the reader performs an accurate range/distance measurement with an accuracy of about 0.05 m and an angular resolution of <1°. The 12 channel sensor array provides measurements up to a distance of 30 m at update rates of >100 Hz. The modulated tags increase the overall sensitivity of the system, since background clutter and noise caused by static radar targets are suppressed. The mobile tags simply modulate the incoming radar signal, resulting in a low power consumption of the tag because to additional transmit power is needed. This allows battery operated tags, lasting several months.
EXPERIMENTAL RESULTS
Field measurements for all systems were conducted in the RAG test mine in Recklinghausen and allowed to evaluate the performance of the individual sensor systems under mining conditions. In the test mine the single sensor systems were mounted on a side-dump loader and different test scenarios have been evaluated. In the following, the results of these field tests are presented for sensor subsystems.

EM-BASED LOCALIZATION SYSTEM
The EM-based localization system was mounted on a side-dump loader. The frame antenna for the magnetic RSS system and the radar based RTOF module were both included in one housing – the so called electromagnetic point of detection (EPOD) unit. For the measurements two of these EPODs were mounted on the side-dump loader, one at the front and one at the back of the machine as shown in Figure 10 and Figure 11, while the RFID antenna was placed at the top of the side-dump loader above the driver seat. The UCAS control unit was placed inside the vehicle as illustrated in Figure 12. The mobile tag for the EM-based localization system is depicted in Figure 13 attached to a corresponding power supply. In addition there are also RFID vehicle tags among one vehicle self-tag that is placed inside the machine and that must be found and identified by the system in order to work.

Figure 10 Front view of the side-dump loader with the attached EPOD and the UHF RFID antenna on top.

Figure 11 Second EPOD mounted at the rear of the side-dump loader.

Four elliptical zones are distinguished in the EM-based localization system: a safe zone for distances above 100 m, a caution zone covering the range from about 10 to 15 m up to about 100 m, a warning zone for distances below 15 m and finally a critical zone at about 5 m around the vehicle. The critical zone around the vehicle is controlled by the oscillating magnetic envelope that is created by the two EPODs and whose strength is measured by the mobile tag. If a tag is penetrating into this zone i.e. a certain magnetic field strength is reached, a stop signal is given to the driver of the machine. The following warning zone is supervised by the RTOF radar component of the system and the subsequent caution zone is monitored by the RFID module. The latter identifies if a person or vehicle tag breaches the safe zone at distances below 100m.
Figure 12 UCAS control unit placed inside the side-dump loader.

Figure 13 Mobile person tag for the EM-based localization system with attached power supply.

Figure 14 Side-dump loader and the experimentally measured zones of the EM-based localization system.
At first, the side-dump loader was placed in the entrance of a cross-cut and the defined zones described in the previous section were set up. Due to the specific environment, the warning zone was set up to start at 10 m from the rear and 15 m from the front of the machine. With one mobile tag the extensions of the zones were experimentally tested and cross-checked with a laser-based distance measurement device. The position of the side-dump loader and the resulting extensions of the zones are shown in Figure 14. The entry of a tag into the critical zone could be detected with an accuracy of less than 0.5 m while for the radar-based detection of the warning zone an accuracy of ± 1 m has been achieved.

For the caution zone (supervised by the UHF RFID system) different extensions compared to the originally intended and set-up zone have been found as the UHF waves were able to follow curves of roadways and could also be received behind junctions without direct line of sight. This could be related to magnetic materials within the mine, like the steel rails on the roadway, supporting the wave propagation. The detection of tags within the caution and safe zone was less accurate compared to the other zones and also depended on the specific environmental conditions.

Further tests with the running electrical motor of the side-dump loader were carried out and could exclude additional influences of the corresponding EM fields of the electrical motor on the measurement as no deviations to the previous results were detected. Finally, the detection of tags in the critical and warning zones was proven while the machine was driving forwards and backwards. Again, the tags were detected reliably and with repeatable accuracy entering the warning and the critical zone and the resulting actions were triggered by the central control unit.

**SOUND BASED LOCALIZATION SYSTEM**

The setup of the sound based localization system consisted of six loudspeakers mounted equally distributed on the side-dump loader as illustrated in Figure 15 and Figure 16. The mobile tags were mounted on tripods for the stationary measurements (see Figure 15) and were later carried by test persons for the moving tag measurements. The base station, which contains the signal processing electronics and a computer executing the signal analysis was placed inside the side-dump loader.

For the first stationary measurement two zones were defined: a critical zone (grey) and a warning zone (white). One tag was placed outside these zones, three more inside the warning zone and a fifth one at the border to the critical zone. The results of the measurement are shown in Figure 16 and demonstrate that all tag positions are estimated reliably and consistently. The results for the one tag placed outside the zones at the rear of the machine show some bias. This problem could be resolved by further calibration measures.

Additional stationary measurements were carried out by placing all tags within the critical zone first and then by placing all tags in the warning zone. Therefore, the warning zone at the rear of the vehicle was extended slightly to be able to place all tags in it. The results are illustrated in Figure 17 and Figure 18 and prove the reproducibility of the measurements. It was illustrated, that a mobile-tag located in the critical zone stays in the critical zone. Furthermore, a mobile-tag within the warning zone stayed in the warning zone and therefore did not lead to an unintentional stop of the machine.
Figure 15 Setup of the stationary measurements in the test mine. The white rectangles indicate the loudspeaker positions.

Figure 16 Position estimates for the stationary measurements. (Hammer, et al. 2015)

Figure 17 Position estimates for tags in the alarm zone.

Figure 18 Position estimates for tags in the warning zone.

Figure 19 Position and velocity estimates of moving tags. (Hammer, et al. 2015)
In addition to the stationary measurements moving tag measurements were conducted. The sound based localization system provides reliable and Doppler invariant results for tags moving at a quasi-constant velocity as described in the previous section. For the duration of the measurement (about 500 msec) the tag's velocity is considered approximately constant. For the moving tag measurements in the test mine five test persons carrying the mobile tags and hard hat microphones moved in a slow speed \( v < 0.5 \frac{m}{s} \) along a given path set around the machine and within the space behind the machine. Figure 19 presents the position and velocity estimates (indicated by the arrows) of this test. The resulting trajectory represents the actual path of the test persons quite accurately.

Finally, distance measurements were undertaken. Therefore, the five tags were placed at points along a distance between 10 m and 45 m radius, starting at the rear right end of the machine and going along the road way of the mine as illustrated in Figure 20. The results of these measurements in Figure 21 indicate that the 1D radial distances to the machine were very accurate even if the 2D position estimates were not representing the precise positions of the tags. At 10 m the accuracy of the distance measurement was 10 cm, at 20 cm it was 25 cm and at 30 m it lay at 30 cm. For the fourth tag at 40 m the accuracy still lay at 85 cm while the fifth tag at 45 m couldn’t be detected anymore. Hence, the system provides reliable results up to a distance of 40 meters and the results confirm the laboratory distance measurements that had been conducted before.

Figure 20 Setup of the distance measurements.

Figure 21 Position estimates for the distance measurements. (Hammer, et al. 2015)
2D PASSIVE IMAGING RADAR & 2D ACTIVE TRANSPONDER RADAR-TECHNOLOGY

2D passive imaging radar
The test setup for the radar measurements is comprised of 4 iDRR sensors (the mounting is shown in Figure 22). As it can be seen, the 4 iDRR sensors are mounted on each side of the loader. Figure 23 shows the implemented visualization with a model of the side-dump loader. The viewing angle of each radar sensor is included in the visualization as an overlay. This setup allows for wall detection and reconstruction when the vehicle is moving. The radar blind spot regarding the movement direction of the machine can be overcome by the usage of additional sensors.

Figure 22: iDRR mounting with magnetic holders.

Three different scenarios were tested: a static scenario (machine and tags not moving), a dynamic scenario (machine moving) and a dynamic scenario (tags moving). Two different dynamic scenarios are necessary to show the performance of both the passive radar and the active radar using tags.

Static scenario: The front right oriented sensor clearly shows supporting beams of the tunnel. (Figure 23). The wall itself is hardly visible. What seems to be a variation of the measured signal at a single location is the evaluation of a set of peaks around a reflecting structure, as the measured elements. To identify exact positions it is necessary to model detected elements according to their typical radar signature.
**Dynamic scenario, moving vehicle:** The vehicle moved quite slowly with about 10 cm per second. Due to the bumpy roadway, the movement direction of the vehicle was not exactly straight and the driver needed to correct the movement direction continuously. However, the tunnel wall can be identified clearly (Figure 24). Further model based data analysis and transforming of the coordinates from the vehicle based to an infrastructure based coordinate system will stabilize the measurements.

Slow moving scenarios are beneficial to identify and track objects in radar measurements. Due to the machine's movement the effective reflecting centers are changing slightly. Combined with a high measurement rate this allows for the statistical analysis of the data. While the accuracy which can be derived by the sensor is specified to 5 cm, this can only be reached in static measurements. In moving measurements the imaging radar introduces slight errors, since a set of single radar measurements is required to form a consistent image. Therefore it is important to account for the movement speed of the vehicle (especially at high velocities). However, it could be shown that the principle detection of passive objects can be effectively accomplished by the radar imaging technique.
2D active imaging radar

The iSWR system was mounted on top of the side-dump loader. In the visualization, the sensor is situated at the grid origin. The viewing angle is towards the back of the loader, with +/- 90° to the side. In the visualization, the tag position is drawn as an overlaying black square. The cluster data of the passive radar is shown as well.

Static scenario: Figure 25 shows a static measurement situation with the iSWR tag located at about x = 5.7 m, y = 1 m (white arrow). The tag is being carried by a person holding the tag near to its body in front of the chest. The iDRR are measuring approximately at the height of the human’s hip. The position within the graphic can be estimated with about 20 cm accuracy. It can be seen that the iSWR position is a little bit closer to the machine than the partly overlaid iDRR clusters. The combination of multiple measurements and a statistical analysis allows for the detection of the center point of the reflections with higher accuracy.

![Figure 25: Static position scenario. Comparison of iDRR clusters and iSWR tag measurement (black square). The iSWR tag position is emphasized by the white arrow.](image)

Dynamic scenario, persons moving: Figure 26 shows three tags with their respective positions. The tags are carried by humans who are slowly moving. It can be seen that the position is changing; the direction is marked with white arrows. In the visualization the measured position estimates (dots) are shown about 3 seconds, before they fade out. The comparison of the measured position with the shown clusters of the iDRR sensor shows a deviation. One of the sensors is not within the measurement range of an iDRR sensor. The other two tags are within the measurement range of the rear left looking sensor. However, due to different delays in signal processing between the different radar types and also due to different handling times, the detected tags are ahead in time to the imaging radar clusters. The future data fusion system must consider this delay.
Further experiments showed that the iSWR sensor is able to detect all tags regardless of their mounting height. The tests showed that the tags must have a line of sight. Moreover, it has been found that position detection is possible even at almost 90° to the side of the sensor. However, this is not representative since in real underground scenarios the radar will be mounted within considerably more massive housing and this will cause shielding effects.

**Radar based collision avoidance**

The two radar types are perfectly suitable for collision avoidance systems. The 2D passive imaging radar allows for detection of all backscattering objects. It enables also object classification and object tracking as long as the single measurements correlate properly. In slow moving scenarios this is typically the case. Slowly changing scenarios also make it possible to use statistical methods to combine single measurements. Furthermore, it is possible to filter ambiguous sensor data by using on site context knowledge to model the measured scene.

The active radar, as tag based system, offers detection of all tags having a line of sight towards the sensor. Due to the low radar frequency, tags may even be slightly masked. With the limited antenna size, the directionality is limited. This will reduce the effective detection range, but allows detecting tags within underground tunnels over the full height. Thus, close tags can be measured regardless their elevation towards the sensor.

CAS often differentiate between warning zones; the closer the target, the more elevated the warning level. This concept can be easily integrated with the presented radar sensors.
CONCLUSION

The aim of the FEATureFACE project is the development of a collision avoidance system which builds upon different technologies. By that, a diverse redundant system combining the advantages of each technology is being created. To achieve this, multiple technologies have been assessed and a concept has been created, which focuses on the most promising single technologies. These technologies are:

- multiple EM-based positioning and detection techniques (UHF RFID, 2.4 GHz RTOF radar, magnetic field strength localization)
- sound-based localization using acoustic signals
- passive and active 2D imaging radar

By using these technologies simultaneously in a combined system, a diverse redundant system is created. If one system fails, there are at least two other systems which guarantee the functioning of the system. This increases the safety of the collision avoidance system dramatically.

Furthermore, the technologies are chosen in a way that the disadvantage of one system can be compensated by at least one other system. While the RFID technology is very robust with regard to body-shielding effects and multi-path propagation it is also rather imprecise. The EM-based radar and the sound-based positioning system, however, compensate for the lower accuracy of the RFID system while suffering from body-shielding and multi-path propagation effects. By employing both, EM-based RTOF measurements and sound-based RTOF measurements, a physical diverse redundancy is created by employing different physical principles. Furthermore, the 2D active radar introduces a system which is very robust against multi-path propagation and operates in a different frequency band than the other systems, introducing yet another redundancy to the system. The 2D passive radar system enables the detection of persons even without tags on them, so even if in one condition a tag fails, the person can still be detected.

The sensor systems based on these technologies were developed in the first half of the project. The principles of each technology are outlined in this paper, as well as the role of each technology in the context of the overall FEATureFACE system. During the development phase, laboratory measurements and field tests were made in order to verify the envisaged performance of the systems. These measurements are presented in this paper and test setups and measurement results are given. It can be seen that each sensor system has its specific advantages and characteristics, which are uniquely important for the respective role the single system plays in the overall system context.

OUTLOOK

The next steps in this project will attend the optimization of the sensor systems and testing of these in mining environments. By that, specific requirements in underground mining can be incorporated into the system design. An optimization of both, hardware and software modules will be done.

Concerning the used radar system, the usage of digital beam forming radar will be evaluated. This is a promising technology since it allows higher measurement resolutions in distance and angle.

Furthermore, the integration of all systems into the overall FEATureFACE system will be prepared. Mechanical and electrical interfaces will be defined and implemented which will allow the combined usage of each sensor’s data. A central processing unit will gather all sensor data (see Figure 27) and combine them into one single visualization. This combined representation
will provide consolidated information for the position of all tags based on the measurements of each single system. Based on this information the system will be able to generate a stop-signal if a person is detected in the critical zone, which then can be fed to the mining machine in order to stop the machine immediately.

Figure 27: Concept for the integration of all sensor data.

In the future, the complete system will be integrated on a SANDVIK road header to assess the quality of the system and to identify optimization potential. By shrinking the subsystems and integrating them into shared housings, a more efficient and more robust system can be achieved.

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