Chapter 2

Safety in Mining

2.1 Introduction

The safety of personnel and the avoidance of accidents is of primary importance in any industrial undertaking. Some industrial sectors are more accident-prone than others, with mining being one of the most dangerous industry sectors. One of the fundamental problems in mining safety is the large number of accidents involving large/small machinery and personnel. Such accidents are termed *close proximity accidents*. This chapter presents the causes of these accidents and the current approaches used to address the problem. These approaches aim at improving situation awareness and thus preventing close proximity accidents. Finally the chapter concludes with a presentation of the fundamental aspects of the approach presented in this thesis and a description of the hardware used for its implementation.

The following three main points are presented in this chapter:

- Background information about the reasons why truck-related accidents occur in the mining environment. Special attention is given to the so-called close proximity accidents and representative examples are shown.
- Types of protection systems to avoid truck-related accidents. The focus here is to generally describe the available technologies based on the sensing principle they use, rather than to present specific implementations.
- The hardware as used in the experimental parts of the thesis. Furthermore, a brief description of a protection system based on this hardware is given to provide background information about the possible localisation capabilities of the developed system.

Figure 2.1: Machine/personnel interaction in a mine — Typically personnel in mines has to interact with large machinery, for example mining haul trucks, as shown here.

2.2 Causes for mining haul truck related accidents

To date, the interaction between machines and personnel poses a significant accident risk in mining operations. The necessity for personnel to work very close to large and heavy machinery such as mining trucks, a situation as shown in figure 2.1, leads to an increased accident risk. Presently there is still a significant number of truck-related accidents occurring in the mining industry, as table 2.1 shows for United States of America (U.S.A.) mines for the time span 1997 to 2006. The numbers presented are obtained from the Mine Safety and Health Administration (MSHA) [58].

Table 2.1: Number of accidents and fatalities in United States of America mines

Year	**'97**	**'98**	**'99**	**'00**	**'01**	**'02**	**'03**	**'04**	**'05**	**'06**
Total number of fatalities	91	80	90	85	72	69	56	55	57	72
Powered haulage related accidents	35	29	23	30	23	22	15	15	24	15
Truck related accidents	16	11	12	10	6	9	6	4	8	3

Different causes exist for accidents that are related to mining haul trucks. One example is fatigue-related accidents. Drivers typically work for 8 or 12 hours shifts and sometimes have micro-sleeps[1] due to fatigue, especially during night-shifts. The simplest and probably most effective approach is to allow sufficient rest for the drivers. Another approach is to monitor brain activity using Electroencephalogram (EEG) [15]. If the alpha waves on the EEG disappear, it can be assumed that the person monitored is fatigued. Another method is eyelid monitoring, where the percentage of eye closure is evaluated. This is an indirect measure of operator fatigue. There are a number of systems based on this principle that are currently available [88]. The sensing elements can be built into a glasses frame, requiring the operator to wear the purpose built glasses. Alternative systems use external cameras mounted in the drivers cabin monitoring the operator's eyes. Another indirect approach to detect fatigue is using external variables such as the steering behaviour or throttle and brake behaviour. Another system monitors the number of alarms issued by a safety system monitoring the truck drivers' behaviour [1]. This system monitors if the driver stays in predefined driving corridors and issues an alarm as soon as the driver leaves this corridor. All such incidents along with the speed and position of the truck are recorded continuously. Analysis of the data, individual to each truck driver, allows detection of changes from the normal behaviour of the driver [95]. It remains to be seen how much these changes can be attributed to the fatigue problem. For example, they might be related to the environment (bad or narrow road). The main issue with systems measuring fatigue indirectly may be the reaction time to detect fatigue. Such systems will need some time to evaluate whether fatigue is actually occurring, as some non-normal events have to occur, before an alarm can be raised.

Equipment that is faulty or not properly serviced is another cause for accidents. Unfortunately, accidents that can be linked to such problems still occur today. It seems that this issue is strongly related to the corporate culture of mine management. A change in the culture of how a mine is run and how the equipment is maintained should be able to reduce accidents based on insufficient servicing. Structural problems and faults related to trucks having components that cannot stand the stress imposed are rare.

Incidents caused by alcohol and drug consumption are also occurring. Although the consumption of drugs and alcohol is prohibited while on shift or in the mine, incidents that are attributed to drugs or alcohol still happen. It seems that there is no common standard on how to handle alcohol and drug abuse and that each mine has its own procedures in place on how to tackle this issue. Procedures may include pre-employment checks and/or random alcohol and drug tests. A consensus exists that the education of miners with regards to the negative effects of alcohol and drugs as well as living a healthy lifestyle is a key

[1] A commonly used definition for micro-sleep is: A lapse from wakefulness into sleep that lasts just a few seconds.

(a) (b)

Figure 2.2: Bad weather conditions in a mine — Picture (a) shows two trucks at the crusher surrounded by fog. The weather conditions on the haul road can be very difficult to drive in when rain and thick fog are present, as seen in (b).

component to reducing the abuse of alcohol and drugs, and thus also reduces the incidents caused by them. MSHA as part of the Department of Labor (DOL) has recently proposed a regulation to address this issue [57], whereas the mining industry seems to be divided about having compulsory regulations in place. Smaller mines fear the costs associated with the introduction of such a regulation. Furthermore, this regulation will affect only U.S.A. mines, leaving out the rest of the world.

The health of the operators is another possible factor for accidents. Drivers may turn up sick to work or have a disease or illness not yet diagnosed, which may have an influence on their capability to concentrate and on their reaction time. The risk of having miners turn up sick to work may be higher in mines where the economic dependency of the miner himself on the job in the mine is higher. Education of the miners to live a healthy lifestyle, along with the provision of a safe, healthy work environment and fair pay, is a key component to reduce incidents related to this issue.

The environmental conditions present in the mine also contribute to a number of accidents. This is the case in many mines located in regions with heavy fog, dust and rain. Rain and fog, as well as dust in the drier regions of the world impair the drivers' view. Figure 2.2 shows an example of the harsh working conditions in which truck drivers need to work.

Large mines have a large number of mobile equipment such as trucks and light vehicles. This creates situations where several of these machines are grouped together, for example at a shovel or in the parking yard. Figure 2.3 shows an example where a multitude of trucks, light vehicles and several shovels can be seen. Very complex interactions between equipment can occur in such an environment. One typical example is the truck-shovel

Figure 2.3: Complex machine interactions in a mine — A lot of mobile equipment operates in larger mines alongside each other and has to interact with each other. To further complicate the situation, drivers can leave their vehicles and become exposed to the larger machines. Note that the small white dots in the picture are light vehicles.

interaction. In this case the truck operator has to move the truck to a place indicated by the shovel operator. This task requires high attention and concentration since the shovel bucket will be moving. At the same time, other equipment such as dozers may be operating nearby or other trucks may be approaching the shovel. It is easy to imagine that accidents occur in such an area with such complex interactions.

The practical aspect of this thesis targets one of the main causes for accidents related to trucks: the large size of these machines and the limited visibility the truck driver has from the driver's cabin. Due to the geometry of the truck and the location of the drivers cab, large areas around the truck become *blind spots*. These are areas where the driver has very limited or no visibility from his position, even when using the rear view mirrors. Figure 2.4 shows the actual blind spots for a Komatsu 730E truck, a commonly used truck in mines. Not shown is the area under the truck itself, which also poses a large risk especially to maintenance personnel working underneath the truck. All blind spots form a danger to safety because objects as large as a light vehicle can virtually hide there, being invisible

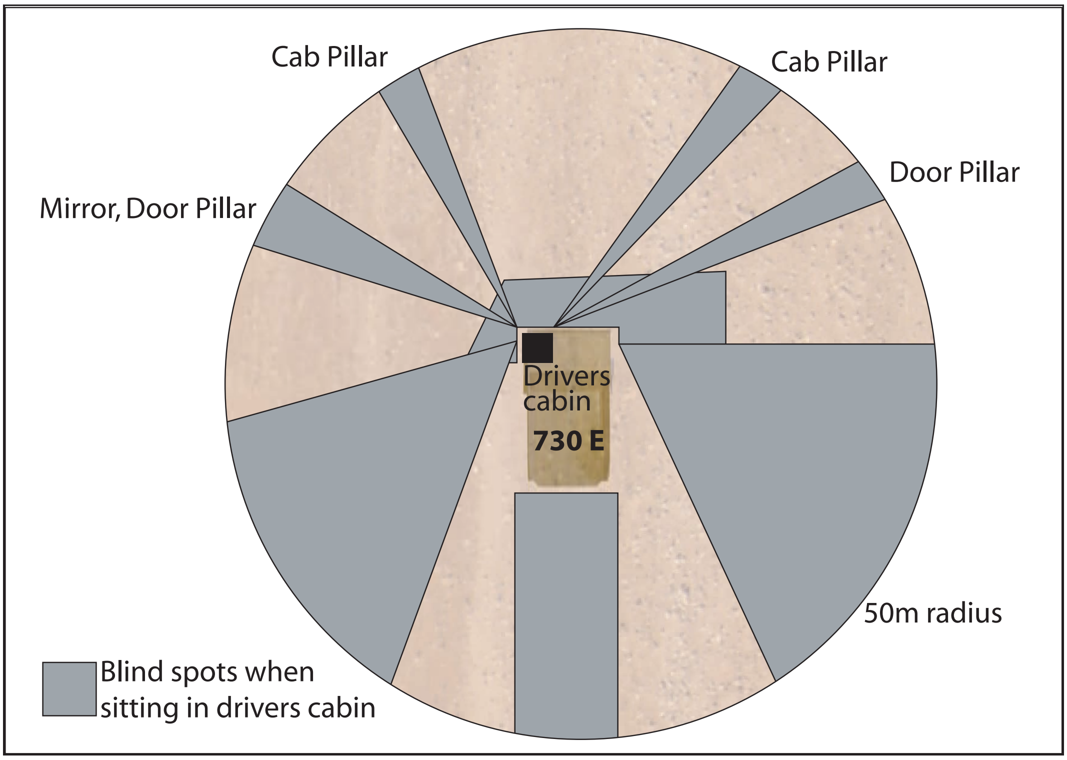


Figure 2.4: Typical blind spots layout for a truck driver — Here shown for a Komatsu 730E mining dump truck. Note that the personnel also has access to the area under the truck itself.

to the truck driver. When a truck driver starts driving he can be unaware of objects or people being in the blind spots (see figure 2.5) and subsequently collide with those objects or people. Accidents similar to the ones shown in figure 2.6 and figure 2.7 happen because of this reason, often combined with some of the other factors previously described. Because of the reasons detailed above it is clear that the mining industry will significantly benefit from a system that can reliably detect resources in close proximity to large machinery. Such systems are called Close Proximity Systems and can be defined as follows:

> A *Close Proximity System* is a system that provides an indication or warning to the operator of a dangerous machine (truck), that someone or something is in close proximity to the machine (truck) and will thus allow the operator (driver) to take appropriate actions to avoid accidents.

The main objective of a Close Proximity System (CPS) is to *reliably* provide the warning to the operator of the large machine when in proximity to other resources. Reliable in this context refers to a system that robustly detects resources in proximity and that may not generate false alarms.

Figure 2.5: Personnel operating in a blind spot — This picture clearly shows how a truck driver sitting the cabin cannot see the person behind the truck.

Figure 2.6: Accident in a mine (1^{st} example) — A truck ran accidentally over a light vehicle. The driver of the truck cannot see the vehicle from the cab. The picture is taken from [2].

(a) (b)

Figure 2.7: Accident in a mine (2^{nd} example) — Picture (a) shows an overview of the accident scene. The haul truck to the right in this picture accidentally drove over a light vehicle. Picture (b) shows a close-up of the light vehicle underneath the haul truck.

2.3 Requirements for a Close Proximity System

When developing a protection system, or more specifically a CPS, a number of factors have to be taken into account. Such factors can be categorised into functional requirements, technical feasibility and economical viability. All of these factors must be taken into account when designing such a system.

Functional requirements specific to a CPS include the following:

- The system should provide alarms with high reliability.
- The system should not issue false alarms or, especially false negatives.
- The system should cover 100% of the dangerous areas.
- The interface for the operators should be easy to read and understand.

All of these four factors are of critical importance. Obviously a system should provide alarms with a very high degree of reliability as this is its main functionality.

False alarms, especially false negatives, are not acceptable. For example, if a person is in close proximity to a truck and in potential danger, yet the system issues no alarm, then no protection is offered. Therefore protections systems tend to be overly careful. The opposite error, a false positive where an alarm is generated although no intruder is in the dangerous area, can be more annoying to the driver. Over time, the level of trust the driver places in the system may be reduced. This in turn may lead to a situation in which the operator ignores the alarms, which is also not desired.

Area coverage is also of great importance. For economical and technical reasons, it is often desired to cover 100% of the dangerous areas with one type of system under all possible operating conditions. This reduces the cost and complexity of the system. From a functional point of view it is important to know the exact area coverage of the system. A secondary system can also be installed if it is known that under certain circumstances the primary system will not cover 100% of the dangerous areas. However, this adds complexity and cost to the overall system.

The function of a well designed operator interface is not to be underestimated. Poorly designed interfaces may lead to a low acceptance rate by the operators. The design may be poor for different reasons, such as a wrong choice of medium used to relay the information to the user. For example, a monitor that cannot be read well because it is mounted in a very bright environment. Another reason may be that too much or too little information is conveyed to the operator. A well designed operator interface will ensure quick and appropriate reaction from the driver if necessary, which is the ultimate purpose of the system. The design of an adequate operator interface, although important, is not investigated in this thesis.

The main technical requirements for a CPS can be summarised as follows:

- The system should be fail-safe. A minimum requirement should be to detect and indicate malfunction.
- The system should offer a minimal degree of redundancy.
- The system should have low power consumption when fitted to personnel.
- The system should need minimum maintenance.

Fail-safe systems have the capabilities to detect any malfunction and can revert to a safe state so they do not harm anyone. This is very important for moving machinery. For a CPS this probably simply amounts to indicating to the operator that the system is malfunctioning to make the user aware of the disturbance and the risks associated with this problem.

Redundancy is required to ensure that the system is still operational if a critical component of the system is damaged, not working properly or not working at all. It is desired to have the CPS in an operational state 100% of the time. Therefore a certain degree of redundancy is required.

Low power usage is especially important for hardware fitted to personnel, where it is desired to have the hardware as small and lightweight as possible. If the hardware uses a lot of power, big and heavy batteries are needed, or the batteries have to be changed during a shift. This is not a good option as this might be forgotten and therefore protection through the CPS might not be present anymore.

Furthermore, a CPS that works continually without requiring a lot of maintenance is more likely to be accepted as it does not interfere with the normal working routine of the operator.

Economical requirements of a CPS include the following:

- The system should be low cost so that it will be accepted on the market.
- The system should require little maintenance to reduce the maintenance cost.
- The system should be easy to decommission and be environmentally friendly or recyclable, thus reducing the cost at the end of the product life-cycle.

2.4 Types of protection systems currently available

To address the safety problem arising from mining trucks, or in general from vehicles like passenger cars or other machinery, different types of warning systems (proximity systems) are either readily available or under development. The National Institute for Occupational Safety and Health (NIOSH) investigated the functionality, advantages and drawbacks of the available systems [76] for the mining sector. In general, safety systems can be grouped into the following categories based on their sensing principle:

- Global Positioning System (GPS) based systems
- Vision based systems
- Radar based systems
- Ultrasonic based systems
- Radio Frequency (RF) based systems
- Laser based systems
- Magnetic field based systems

2.4.1 Global Positioning System based systems

GPS based systems require all mobile equipment and personnel to be fitted with GPS receivers. The absolute position of the agents is communicated either to a base station and from there to the other agents, or it is directly communicated between agents within range of each other in a Peer-To-Peer (PTP) manner, for example via User Datagram Protocol (UDP) messages. Such systems have the need to reliably obtain position data for each agent and to communicate it to the other agents, most importantly the source of danger. This solution used to be expensive and not fail-safe since it relies on each object having an operational GPS unit and complete GPS coverage in the mine. Advances in technology have made it possible to develop systems at a reasonable price with high operational reliability [1, 51, 62, 63]. However, an unsolved issue remains that GPS based systems will in many cases have poor satellite availability or multipath related issues when the operator is very close to large machines or, in the case of personnel, under the trucks. In such situations the position of an agent might not be available or it might be calculated incorrectly. These systems are not capable of reliably protecting agents at very close range to big machines.

2.4.2 Vision based systems

Vision based systems require computer based image recognition of an object in the proximity zone, which can be difficult and unreliable in varying outdoor light conditions. Alternatively, this approach requires the driver himself to see the intrusive object or agent in a small cab-mounted video screen that in poor lighting conditions can be unreliable as well. Recently, camera based systems have become more popular in the private sector for passenger cars protecting the area directly behind the vehicle. A small dashboard integrated Liquid Crystal Display (LCD) displays the area immediately behind the car when reversing. In the context of CPSs for mining, the potential of vision based systems lies in complementing add-ons to verify and confirm the presence of an agent once the agent has been detected by another system.

2.4.3 Radar based systems

Radar based systems are based on range and bearing sensors actively detecting an object in proximity to the trucks. One promising approach [78] utilises a low frequency short range radar. A commercial version of this type of radar operates at 5.8 GHz and can detect objects at ranges up to 8 metres within an arc of 55 degrees horizontal and 20 degrees vertical [71]. It is fitted with hardware to provide a visual and audio alarm if an object is within the detection area. The output of a detection algorithm is then used to turn the appropriate camera monitoring the corresponding area. One failure mode is that it is possible for agents to walk under the radar beam in certain situations, thus not being protected at all. Since the resolution of the radar is very poor at this frequency it is very difficult to avoid false alarms. The resolution could be improved by using Millimeter Wavelength Radar (MMWR) or lasers. However MMWR are still very expensive.

2.4.4 Laser based systems

Laser based systems have not yet been employed for CPSs. Analog to radar, the laser is a range and bearing sensor. Using laser it is possible to monitor a certain limited region and to detect the distance and the angle to objects or agents. Appropriate processing software should be able to detect agents in the dangerous zone. Similar to radar based systems, one sensor (radar or laser) will in most cases not be enough to ascertain in the case of trucks that 100% of the dangerous area is covered. A laser based system would most likely require the laser to be mounted at low heights, which in a mining environment is often dusty and would therefore make the detection of agents more difficult, if not impossible (false alarms). A laser based protection system is found in the area of truck guidance, where the laser tracks the position of the mining truck with respect to the road boundary [59]. Here the laser is installed at high altitude to minimise the negative impact of dust.

2.4.5 Ultrasonic based systems

Ultrasonic based systems are popular for passenger cars and trucks (heavy goods vehicles) collision avoidance. This type of system was invented by Volkswagen (VW) and is known under the name Parktronic [94]. Acoustic Parking System (APS) is a parking-assistance system installed on some Audi vehicles also based on ultrasonic. These systems use ultrasonic sensors embedded in the front and rear bumpers to measure the distance to nearby objects. They emit an intermittent warning tone (and in some other luxury marques, they offer visual feedback through LCDs on the dashboard and above the rear window) to indicate how far the car is from an obstacle. The warning tone becomes faster with decreasing distance. It first sounds when the car is approximately 1.5 metres from the obstacle and operates at low speeds only. When the distance is very small (about 25 cm) the tone becomes continuous. Ultrasonic systems have not yet been employed in CPS for mining applications. This is most likely due to the limited range these sensors possess, the expected problems in the harsh mining environments where dust may cause a significant number of false alarms, and the possible occurrence of noises at ultrasonic frequencies which would interfere with such a system.

2.4.6 Magnetic field based systems

Another type of protection system is the magnetic field system. These systems consist of a transmitter and a receiver. The transmitter induces a magnetic field, usually around the dangerous machine. The receiver is worn by personnel or attached to a light vehicle that is to be protected. Basically, the receiver is a magnetic field strength meter which will respond at certain thresholds of the magnetic field as the dangerous machine is approached.

An alarm in the form of a sound, flashing light or even vibration is generated to warn of the imminent danger. NIOSH tested such a system [81] for underground application and also as a CPS to protect light vehicles from trucks. A drawback of the tested system is the limited range, with about 10 m maximum range for reliable protection. Also, high transmission powers of above 50 watts were used to reach the described results in the surface mining test for use as a CPS.

2.4.7 Radio Frequency based systems

RF based systems require all mobile equipment and personnel to wear a Radio Frequency Identification (RFID) tag that will respond when in the proximity or communication zone of a RFID tag reader. For a CPS the readers would be typically attached to the truck while the other agents (personnel or light vehicles) would carry the RFID tags. Although there are a few commercial systems based on this approach, most of them only provide an indication that an agent is in the proximity zone. The detection of the location of the agent may require additional hardware and accuracy may be an issue. An example of a simple system, just indicating the presence, but not the accurate location is CAS-CAM/RF® [2].
Two different principles are currently pursued:

- Time-of-Flight (TOF) / Time-Difference-of-Arrival (TDOA) based; and
- Signal strength based

TOF systems measure the time it takes for the RF signal to travel between transmitter and receiver and then evaluate the distance between them from the time measured. A robotics localisation example using this technique is shown [49, 54]. To be able to calculate the time of travel the clocks on the transmitter and receiver have to be well synchronized. Alternatively, round-trip measurements where a transmitter sends out a message and waits until it gets a response can be used. But for this approach it is necessary to estimate the delays in the receiver very accurately. If, for example, the travel time of the signal is in the order of several nanoseconds, but the processing in the receiver can be evaluated with microseconds accuracy only, the resulting estimated distance will be very inaccurate and most likely not very useful.

Signal strength based systems use the received power of the RF signal to estimate the distance between transmitter and receiver. This is the type of technology used in this thesis for localisation and tracking purposes and will therefore be discussed more thoroughly in later sections and chapters.

The advantage of using RF based systems in general is that it is possible to provide the RF signal even in very remote and difficult to reach locations such as under the truck.

Also, there is little effort needed regarding installation cost and the number of transmitters to ensure a high coverage of the dangerous area.

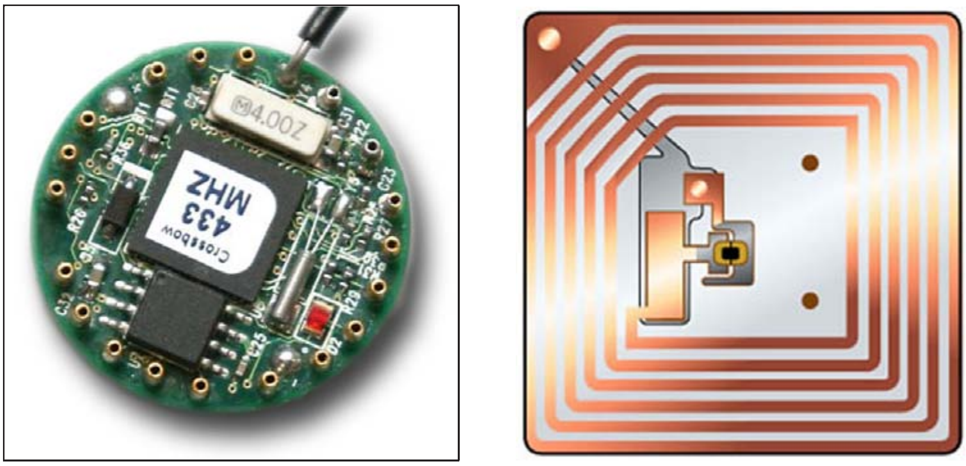
Generally speaking RF based systems consist of at least one transmitter and one receiver. Nowadays it is common to have transceivers (transmitter + receiver combined in the same hardware) for both units. RF based sytems usually provide unique identification of the individual transceiver, are small in size, lightweight and can operate with low power consumption.

The systems using RF can be divided into two categories:

Active systems: These systems provide power to both units, the transmitter and the receiver. They can reach high maximum transmission power and therefore high transmission ranges when compared to passive systems. Active systems can have a processor on board for computation and their transmission power can be varied [24]. An example transceiver is shown in figure 2.8(a). To save energy some active systems can enter sleep modes and wake up only when necessary, for example to process an incoming RF message. Additionally, these active systems might offer the capability to store data on the tag itself. Some active systems come with other built-in sensing capabilities such as temperature and humidity.

Passive systems: The main feature of passive systems is that the RFID tag itself has no power supply. Instead it draws the energy necessary to process the information from the sender, and to send a reply, from the incoming signal itself. This consumes some of the energy available from the incoming signal. The main implication of this is that the communication distance is very limited and generally smaller than that of active systems. On the other hand, such systems do not have the need to change batteries or to provide a constant power supply and are therefore easier to maintain. Their use is widespread in retail to protect goods from being stolen. Another popular application is in running races such as marathons to obtain the timing of the competitors. An example tag is shown in figure 2.8(b).

The distinction between active and passive tags has implications for the applicability of the individual type of RF sensor to a specific target application. Passive RFID operation is dependent on the availability of a strong enough signal from a reader to communicate, while active RFID tags can be permanently powered up and operational. Furthermore, readers for passive tags send up to 1000 times the power when compared to active tags because of the need to provide power to the passive reader. They reach maximum ranges of only a few metres compared with up to 200 m or more for active technology. However, inter-tag communication to exchange information between active RFID tags themselves is possible and might prove a useful feature for many applications, for example localisation.



(a) (b)

Figure 2.8: RFID hardware — An active RFID tag with processor and variable transmission power capabilities is shown in (a) and a passive RFID tag is shown in (b).

RFID tags, both active and passive, typically operate in the Industrial, Scientific, and Medical (ISM) band. Directly related to the choice of frequency is the power necessary to guarantee a certain communication range, as the power needed to transmit a signal for a certain distance increases with increasing frequency.

2.5 Future of Close Proximity Systems

Future improvements for CPSs lie in the area of automated and intelligent interaction with other CPSs and the systems they protect and interact with. Two possibilities to enhance CPS functionality are apparent:

Firstly, the system could provide advice to the truck driver how to resolve a dangerous situation. The Traffic alert and Collision Avoidance System (TCAS) used in the aviation industry for planes above a certain weight is an example of a protection system of the next generation. Here the systems on the individual planes communicate with each other and issue warnings and instructions on how to resolve a dangerous situation based on a coordinated decision taken by both systems. An example of this is the situation where two planes are flying on a collision course. The TCAS might issue advice to one plane to descend and to the other to ascend, thus resolving the dangerous situation. This system only provides advisory information and it is up to the pilot to decide if the instructions given are followed.

Secondly, interaction between the CPS and the truck can be introduced. Recently car manufacturers have started to offer protection systems which actively intervene if a dangerous situation is detected. One example is a system that monitors the distance to the preceding vehicle and engages the brakes automatically if the distance falls below a safe distance. Such an active intervention is still under hot discussion and the regulations and laws governing the behaviour of such systems and especially the liability in case of malfunction are just being introduced. The difficulty lies with the minimum amount of redundancy such systems need to incorporate, so as to ensure that malfunctions do not occur or do not have a serious impact. Situations might end tragically if such a system fails and it is these situations for which manufacturers are seeking protection from liability law suits.

The potential to enhance a CPS with next generation features is great and apparent. As a first step, advisory information could be provided to the truck driver similar to the TCAS. Such advice could be for example in the form of a voice message indicating that it is safe to drive forwards if an agent is detected at the back, or the driver could be advised not to start driving at all. As a next generation step, the CPS could interact with the vehicle and lock the brakes actively if a dangerous situation is detected. Alternatively, it could limit the maximum speed of the truck in areas where agents are detected not in immediate proximity but still at a distance not too far away from the truck.

2.6 Hardware used in the experiments

This section presents the hardware as used in the experiments. The hardware is a prototype implementation of a CPS developed at Universidad Nacional del Sur (UNS) and has undergone a second iteration in the development process with the major change being the switch in operation frequency from 900 MHz in the first generation to 434 MHz in the second generation. This occurred as the maximum range with the 900 MHz nodes was not as anticipated from the technical data of the RF chip [23].

2.6.1 System design

This subsection gives a brief description of the CPS system design which consists of the following parts:

- RF based technology – the received signal strength indicator (Received Signal Strength Indicator (RSSI)) will be used to estimate the location of agents.
- Multiple tag readers will be attached to the truck and detect intruders carrying a tag.
- Personnel will have the tag attached to the helmet, light vehicles will have the tag on the roof of the drivers' cabin.

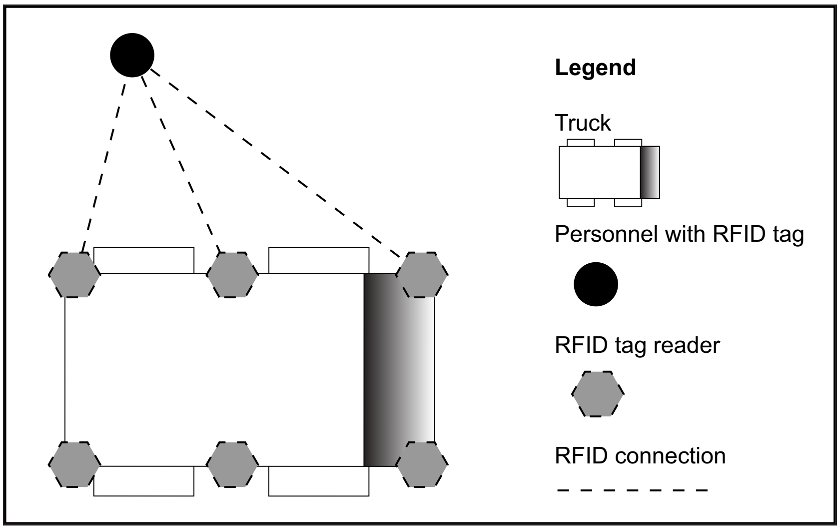


Figure 2.9: CPS system setup — Multiple fixed nodes are attached to the truck and detect intruders wearing RFID tags.

- A central unit on the truck processes information coming from the tag readers and this unit also issues warnings/alarms to the truck driver if an intruder is too close to the truck.

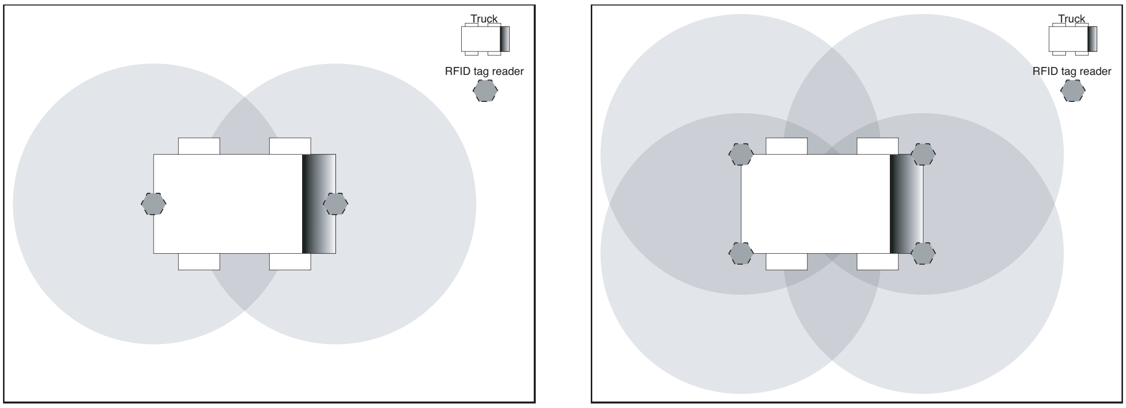
In general there are two types of nodes, the tag readers attached to the truck and the tags attached to the intruders, personnel or light vehicles. The RF part is common to the underlying hardware, though subtle differences exist. The tag readers offer interfacing capabilities to the central processing unit, while the light vehicle node offers interfacing to an external user interface. The general configuration of the proposed system can be seen in figure 2.9. Not shown is the central processing unit which is connected to the individual tag readers and obtains the information from the readers.

The system was chosen such as to offer maximum area coverage, redundancy and also to allow relative localisation of agents.

Area coverage

The use of multiple tag readers ensures that a high percentage of the dangerous area around the truck is covered by the system (see figure 2.10(a) and figure 2.10(b)). Experimental tests confirmed that RF coverage is available even under the truck, giving protection to personnel working in this area.

A simple solution is to use the minimum number of sensors necessary to cover the area to be protected. This can be achieved with two sensors only as shown in figure 2.10(a).



(a) (b)

Figure 2.10: CPS area coverage — (a) Two fixed nodes are attached to the truck and cover the area immediately around the truck. (b) Multiple fixed nodes are attached to the truck and have overlapping operating ranges. The transmission range of the sensors shown here is simplified as the same in all directions, which is not true. In reality the transmission range usually exhibits a dependency on the azimuth angle.

Such a setup does not provide the possibility of accurately localising the agents, as will be explained later on.

A better solution is to increase the number of sensors so that their operational ranges overlap. Such a setup will allow localising of agents and at the same time the area covered is increased when compared to the two-sensor solution. This is shown in figure 2.10(b).

Redundancy

Single sensor solutions are not desirable as a failure of the sensor will result in complete system failure, possibly with drastic consequences in critical systems. To increase robustness redundancy is implemented. System redundancy for the CPS is achieved through the arrangement of multiple tag readers mounted on the truck, so that their operational areas overlap. In the case that one of the sensors drops out or misses a message from an intruder at least one of the neighbouring nodes receives it. The principle of overlapping operational areas is shown in figure 2.10(b). The operational areas shown in the figure are small and the real RF chip used in the hardware for the experimental part has a much larger operational range, which ensures a greater overlap between the sensors.

Location estimation

Through the use of RSSI it is possible to make inferences about the distance between the tag reader and the tag. Chapter 3 presents a more detailed discussion of RSSI, but for now it suffices to know that it is possible to extract range information from the RF signal. As shown in figure 2.9, multiple tag readers will detect one intruder at the same time, and using the range information obtained from each of the tag readers it is possible to reconstruct the position of the intruder. This process is shown in chapter 5.

Although it is necessary for a tag to communicate with multiple tag readers at the same time to be able to localise it, a system as shown in figure 2.10(a) can also offer minimal location information. It is possible to detect whether the intruder is located near the sensor installed at the front or near the sensor at the back. Such a setup is not able to detect whether an intruder is to the left or to the right side of the truck. These ambiguities may be resolved with additional sensors if they are installed as shown in figure 2.10(b).

Transmission power

The RF chip used for the CPS hardware uses very low transmission power with a maximum of only 10 mW. It operates at a frequency of 434 MHz. This frequency band is designated for unlicensed ISM applications [47] in most countries of the world. In Australia the 434 MHz frequency band is not part of the ISM band. However, special legislation allows the unlicensed use of the 434 MHz band for transmission powers below 25 mW [7, 65, 66]. The manufacturer of the RF chip describes the compliance of the RF chip with the regulations for most countries in the world in an application note [22].

Low transmission power is also very important as care has to be taken that the RF signals of the CPS do not interact with electric detonators used in mines. The Department of Primary Industries in NSW (Australia) refers in its Safety Handbook [64] to the Australian Standard AS 2187.2 [89]. This standard specifies for the categories of mobile radios with a transmission power less than 10 W, to which the CPS hardware most likely belongs, that a minimum distance of 20 m from electric detonators has to be kept.

2.6.2 Hardware components

The CPS consists of three main components, each of which will be shown and described subsequently. These components are:

Tag readers for trucks (truck nodes)

Truck nodes consist of a tough aluminium housing to protect the electronics from the harsh environmental conditions present in mines. A special reduced size monopole antenna is located in a white PVC nose, oriented vertically. One of the tag readers for the trucks is shown in figure 2.11. The truck nodes come optionally with a GPS.

Figure 2.11: Haul truck node CPS — This haul truck node also has a GPS installed as can be seen on the black antenna on the top of the node. The RF antenna itself is built into the white nose.

Tags for light vehicles (light vehicle nodes)

Light vehicle nodes, as shown in figure 2.12, are also encased in an aluminium housing for protection reasons. They also come with a built-in GPS, and as they are to be attached to the cabin of a light vehicle, they also have a flashing light built in. A basic alphanumeric display, as shown in figure 2.13, can be connected to inform the driver of the light vehicle of the number of other agents in proximity to the light vehicle.

The core of both the truck nodes and the light vehicles nodes is based on a common RF board featuring a CC1000 RF chip and an Atmega Atmel 128 processor, as shown in figure 2.14.

Tags for personnel (personnel nodes)

Personnel nodes are based on the Chipcon CC1010 RF chip, which incorporates the RF part and a processor on one chip making it possible to reduce the size and the weight of the node. As figure 2.15(a) and figure 2.15(b) suggest, the personnel nodes will be very small in size. This type of node can also have a GPS as an option.

The main features of the hardware are summarised in table 2.2.

Figure 2.12: Light vehicle node CPS — Light vehicle nodes also have a GPS built in. The RF antenna can be seen on the upper left corner of the node. These nodes are mounted on the roof of the vehicle cabin.

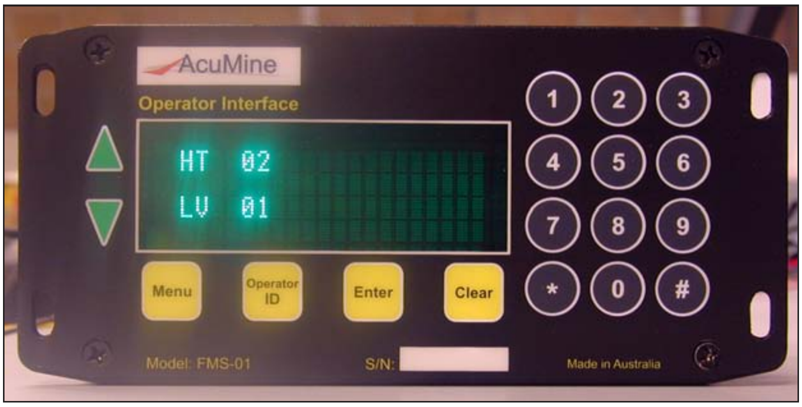


Figure 2.13: Light vehicle operator interface CPS — Using a simple text based interface the number of haul trucks (HT) and light vehicles (LV) in close proximity can be reported to the driver of a light vehicle.

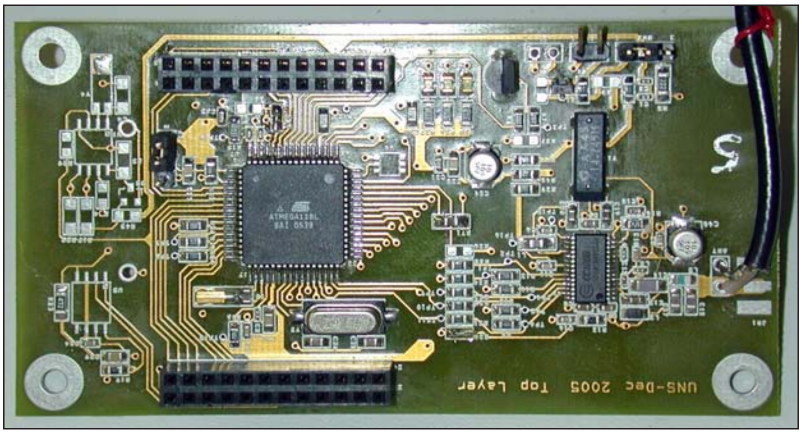
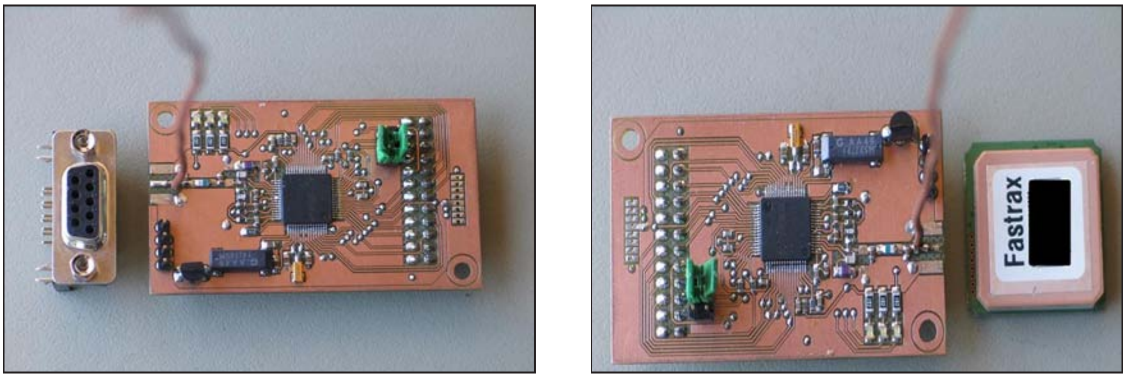


Figure 2.14: Processor board CPS — This board features an Atmega Atmel128 processor and a Chipcon CC1000 RF chip.



(a) (b)

Figure 2.15: Personnel node CPS — (a) The dimensions of the personnel node are very small to allow for potential integration in a helmet. Not shown here is the battery, which must also be included. The DB9 connector in the picture serves to demonstrate the dimensions. (b) The personnel node can be expanded with the add-on of a small-sized GPS.

Table 2.2: Technical data of Close Proximity System nodes

	Truck and light vehicle node	**Personnel node**
Frequency	434 MHz	434 MHz
Max. transmission power	10 mW	10 mW
Max. transmission range	≈ 200 m	≈ 200 m
Processor	Atmega Atmel128	Built-in RF chip
RF Chip (Chipcon)	CC1000	CC1010
Operating system	TinyOS	TinyOS

2.6.3 Note on the inclusion of Global Positioning System in the presented Close Proximity System

As mentioned in subsection 2.4, the position information reported by the GPS [41] in autonomous mode has to be treated with great care when the agent is close to the truck, as it may give a false reading due to multi-path and other effects. Nevertheless, in an open environment, at a certain distance from the truck, the absolute position information can be very good quality. The GPS position and the RF based position can complement each other, with an expected better GPS accuracy for larger distances to the truck and a better performance of the RF based position estimation for small distances.

2.7 Summary

This chapter elaborated on the issue of safety in mining. In particular it explained the main causes of accidents involving haul trucks and presented an overview of current approaches investigated to address the problem. Each approach or system comes with its own advantages and disadvantages and a successful protection system will most likely be a combined system to overcome individual weaknesses. The issue of close proximity accidents occurring due to the limited field of view of the truck drivers was also discussed. For these types of accidents, RF based systems are appealing as they can be used to ensure area coverage in difficult to reach areas in a very robust manner.

The hardware used for the experimental parts of this thesis was also presented. The hardware is RF based and is part of the development of a CPS.

In order to be able to use RF sensors for localisation purposes one needs to describe sensor behaviour in the form of a sensor model. The next chapter presents the RF sensor models developed and most relevant for this thesis.