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ATOM

Airport detection and Tracking Of dangerous Materials by passive and active sensors arrays

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D2.1: ATOM system architecture

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(*): *The dissemination level of this document has been changed from PU (public) to PP (Restricted to other programme participants (including the Commission Services)) due to improve strategy adopted by the consortium in the information and dissemination.*

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1 Introduction

Events such as 11 September 2001 or the hijacking of Air France flight 8969 (1994) and many others brought in the latest years to front the problem of air transport security. This has always been a priority for the EU aviation industry, since airports represent a natural target for terrorist acts. Nevertheless, the airport security measures haven't always been effective and we count many past tragedies which were the result of people being permitted to carry inside the airports explosive materials or weapons. A recent failed attempt occurred last 25 December 2009: a Nigerian man tried to ignite an explosive device aboard a trans-Atlantic Northwest Airlines flight as the plane prepared to land in Detroit. It was unclear how the man, identified by federal officials as Abdul Farouk Abdulmutallab, 23, managed to get the explosive on the plane, an Airbus A330 wide-body jet carrying 278 passengers that departed from Amsterdam with passengers who had originated in Nigeria. However, the man hid the explosives under his pants and managed to elude security checks both in the airport of departure in Nigeria, both in the airport of Amsterdam where he made the transit to change the flight. Today, travellers are only quickly screened by walk-through metal detectors for entering the sterile area, while X-ray machines are used for screening carry-on and checked baggage. After the recent events many airports are installing and requiring the control through the so-called body-scanners that are able to do a complete scan of the entire body of a person. However the system implies the transit of all passengers through the scanner for a period of a few tens of seconds each, which improves security but may have an impact on waiting times for passengers and on issues related to the privacy. The overall objective of ATOM project is to design and develop an innovative detection and surveillance system able to enhance the security level in the airport areas, by detecting hidden hazardous materials/tools (including explosives) and tracking people bringing these materials, without interfering with the normal airport operations; while directly enhancing the airport security, ATOM system will also indirectly contribute to protect aircraft (A/C) from terrorist or other criminal acts.

In the scope of this project the ATOM adjective is used with three different notations:

1) **ATOM final product**: the system which could be hopefully proposed in the market at the end of all industrialization processes following the present studies and development. All the Concept of Operations (CONOPS) provided in this documents from end user partners are related to this final product which will be available on the market in the future.

2) **ATOM system concept** (usually referred as "ATOM system" in this document) which represent the notion and the abstract implementation to demonstrate, in it's validity and feasibility by the ATOM project. The present documents, with exclusions of chapters and considerations provided by the airports CONOPS, is strictly focus on this system concept and refer to it when mentioning the Atom system expression.

3) **ATOM demonstrator** or **prototype**: an ATOM system prototype which will be the result from the project validation activities aimed to demonstrate and justify the validity of ATOM system concept in operative scenarios. The specific characteristics of this prototype will be described in detail in the deliverable D9.1.

2 Operational and functional requirements

2.1 Concept of Operation (CONOP)

A CONOP (Concept of Operation) is an important part of a security system which describes the characteristics of a system from the viewpoint of the end-user. It is a description of how the set of ATOM capabilities may be employed to achieve desired objectives or a particular end state for a specific scenario.

An important part of a CONOP is the operational concept which describes the process of screening. In the following figure a possible high level concept is described.

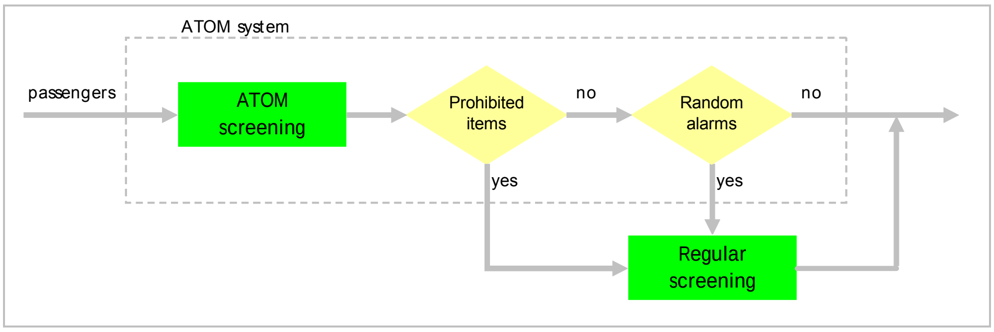

Figure 1 – Process of screening

2.2 Operational requirements

Facing the ongoing threat from terrorism, governments around the world have stepped up efforts to detect concealed weapons before they cause havoc at populated public settings, such as crowded subways, train station, airports, stadiums, and shopping malls. Available new technologies include chemistry-based sensors to pick up the faintest molecules of explosives in the air; passive or active screening tools to detect weapons hidden under clothes or within luggage; and artificial intelligence to go through video surveillance for suspicious behaviours in the crowd, etc. It is certain that none of the technique mentioned can serve as a comprehensive solution for such complicated problem. The diversity of technology provides different solution for specific problem.

In the following paragraphs the high level requirements which should be met by the ATOM system will be described. These requirements, independently from how the security process is actuated, describe the desired effect of the overall security Two airports will be considered. First Schiphol airport and then Targu Mures Airport. These airports are different in many points of view. Schipohol (Amsterdam) is a very large airport, both for passengers flow and for its strategic location in the middle Europe. It is also used from many passengers as a trading point for various destinations. Targu Mures is a smaller airport located in Transilvania (Romania). Our aim is to identified the operational requirements in order to highlight the similarities and eventually the differences.

2.2.1 High level requirements (Schiphol airport)

2.2.1.1 Introduction

In this section the high level requirements will be described. The more specific, low-level requirements depend on the process set up, layout, Concept of operations (CONOPS), etc..

The extent to which the security process is executed could be covered by the following objective:

Security process shall be compliant to the current security services at acceptable quality level, level of perception, process times and cost

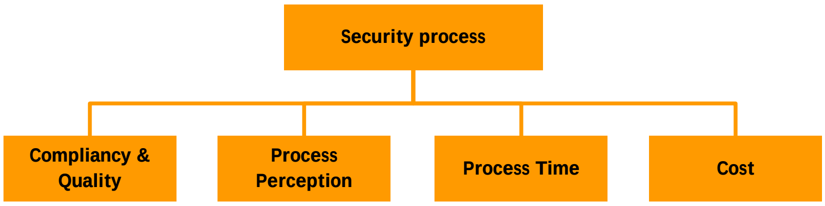

Figure 2 – Objective of the security process

In the current security process the throughput is used as an important indicator in order to avoid long waiting times in the event of high passenger arrival rates.

Because the ATOM concept differ from the current one and there will be no security check points, process time is used as a more general indicator instead of throughput.

2.2.1.2 Compliancy & Quality

Compliancy refers to the articles not permitted to carry into the security restricted area and the cabin of an aircraft. This list is described in the paragraph 3.1.1.

Quality is defined as the extent to which the security system is able to detect the prohibited items from the list in 3.1.1.

2.2.1.2.1 Probability of detection

Probability of detection is the extent to which the security process complies with the EU law and regulations and to which the security system is able to detect the prohibited items from the list in 3.1.1.

The probability of detection of prohibited items shall be at least at the current level.

This means that the overall security process including procedures, personnel, lay-out and equipment should guarantee this detection level. If the overall security process is set up as a combination of the ATOM and the regular system, then this requirement regards the overall security process (see picture below).

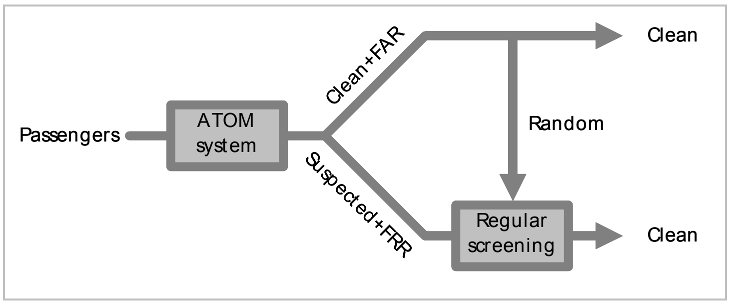

Figure 3 – Overall security process

There will be passengers which need an additional (regular) screening due to assumption of carrying prohibited items, possession of prohibited items or due to false or random alarms. This additional screening could be executed at the regular security check points and is outside the scope of the ATOM system (see also Figure 3). However, the number of passengers which need the additional screening is effected by the reliability of the ATOM system (false alarms or false rejections, see 2.2.1.2.2) and is the subject of quality requirement of the ATOM system.

2.2.1.2.2 False Rejection Rate (FRR)

False Rejection Rate is the extent to which the passengers are wrongly suspected by the security system of carrying prohibited items.

The percentage of false rejections generated by the ATOM system shall be less than 20%.

2.2.1.2.3 False Acceptance Rate (FAR)

False Acceptance Rate is the extent to which the passengers are wrongly cleared by the security system.

The percentage of false acceptances generated by the ATOM system should be as close as possible to 0%.

2.2.1.3 Process Perception

Process perception describes the perception of passengers and security personnel regarding the security process.

2.2.1.3.1 Passenger satisfaction

Passenger Satisfaction is defined as the overall passenger experience of the security process. The following sub-indicators cover the overall passenger perception.

2.2.1.3.2 Security Perception

Passenger satisfaction regarding the security level shall be at least 76% of passengers scoring excellent or good.

2.2.1.3.3 Waiting Time Perception

Passenger satisfaction regarding the waiting time shall be at least 81% of passengers scoring excellent or good.

2.2.1.3.4 Security Personnel Friendliness

Passenger satisfaction regarding the security personnel friendliness shall be at least 85% of passengers scoring excellent or good.

2.2.1.3.5 Security Personnel Satisfaction

Security personnel satisfaction regarding the operation of the security process shall be at least at the current level.

2.2.1.4 Process time

ATOM is based on a concept in which passengers are screened without requiring there cooperation and in which there are no security check points which passengers will have to pass through. This could mean that within the ATOM system the waiting time and the throughput of passengers are non restrictive.

However, the ATOM process of detecting the prohibited items and tracking the movements of people will still claim the capacity and time of the airport security operation (also personnel) while passengers will not experience extra process time. This means that even the passengers are not aware of being screened, the security operation will need extra time for the screening of passengers and cabin bags (data processing, decision and evaluation by personnel, etc.).

In the next table the possibilities are shown.

Process time	ATOM screening	Regular screening
Passenger time	X	✓
Security time	✓	✓

Table 1 – Process time for ATOM screening and regular screening

In this table the only process time which will be described by a requirement is the process time of the airport security operation. Passengers will not have an additional process time in the ATOM process and the regular screening is outside the scope of the ATOM system.

2.2.1.4.1 Process time

The process time which airport security operation needs to execute screening of passengers and cabin bags using the ATOM system shall not delay regular passenger flow. It means that there is no additional process time for passengers.

2.2.1.5 Cost

ATOM is an innovation project which will result in a prototype of an innovative multi-sensor based system. The ATOM system could contribute to the cost objective by (partly) automating the screening process which will lower the number of personnel and decrease the exploitation costs.

2.2.2 High level requirements (Targu Mures airport)

2.2.2.1 Introduction

In this section will briefly be described the high level requirements of Targu Mures Airport. Also some current security systems are described.

2.2.2.2 Information on security system

Due to the limited size of the airport, the current security system foresees that the it is organised in the following way:

- *security staff* (15 persons): airport security agents, supervisors which are responsible for the operations, Airport Security Manager responsible for security processes and how is the process designed
- *Security systems for passengers* : 6 security check points
- Security public guards which we hire according to contracts to execute the daily operation for perimeter area of the airport and for security access control in security restricted areas (42 agents).
- *Security systems for personnel at Transylvania Targu Mures area*: 2 security check points

The possible improvements of actual security system are : throughput, new equipments, less personnel.

2.2.2.3 Data presentation

The current data presentation systems in the airport are:

- *Type of display:* There is a Security Control Center where all security processes can be controlled (Passenger & Cabin Bag Screening, Access Control, Immigration Control, Customs Control, Public guards, police, aprons, car parking). In the security control Center there are 8 displays with max. 16 video images per display.
- *Single or Multiple*: The software installed to Security Control center is able to switch from multiple image to single image per display.
- *Visualization*: all people

2.2.2.4 Security Informative system

The main features of the current airport security informative system are listed in the following:

- *How the data are distributed*: there is a network to distribute only security data to border police, secret service, military police, customs, public guards.
- *How sensible data are treated*: All these data is protected and the above mentioned parties have only access to data which they are allowed to use.

2.2.2.5 Compliancy & Quality

2.2.2.5.1 Probability of detection

The probability of detection of prohibited articles described in Regulation(EC)no 622/2003,no.68/2004 and no.1546/2006 shall be at least at the current level.

2.2.2.5.2 False rejection rate (FRR)

The percentage of false rejections generated by the ATOM system shall be less than 20%.

2.2.2.5.3 False Acceptance Rate (FAR)

The percentage of false acceptances generated by the ATOM system should be as close as possible to 0%.

2.2.2.6 Process Perception

Process perception describes the perception of passengers and security personnel regarding the security process. Process perception describes the perception of passengers and security personnel regarding the security process. The requirements of Targu Mures about the process perception is equal to Schiphol airport.

2.2.2.6.1 Passenger satisfaction

As we saw in the previous sections, passenger Satisfaction is defined as the overall passenger experience of the security process. The following sub-indicators cover the overall passenger perception.

2.2.2.6.2 Security Perception

Passenger satisfaction regarding the security level shall be at least 76% of passengers scoring excellent or good.

2.2.2.6.3 Waiting Time Perception

Passenger satisfaction regarding the waiting time shall be at least 81% of passengers scoring excellent or good.

2.2.2.6.4 Security Personnel Friendliness

Passenger satisfaction regarding the security personnel friendliness shall be at least 85% of passengers scoring excellent or good.

2.2.2.6.5 Security Personnel Satisfaction

Security personnel satisfaction regarding the operation of the security process shall be at least at the current level.

2.2.2.7 The process time

The process time which airport security operation needs to execute screening of passengers and cabin bags using the ATOM system shall not delay regular passenger flow. It means that there is no additional process time for passengers.

2.2.3 Conclusions

In the previous paragraphs the high level requirements are been described. Two airports are been considered. First Schiphol airport and then Targu Mures Airport.

Despite the two airports are very different both in terms of air traffic and of passengers flow, it was seen that not substantial differences are been highlighted regarding the compliancy and quality (probability of detection, FAR, FRR), process perception and process time.

In fact the following table summarizes the main operational requirements described in the previous sections and shows the equalities for the two considered airports:

		Schiphol	**Targu Mures**
Compliancy & Quality	Probability of detection	Current level	Current level
	False rejection rate (FRR)	20%	20%
	False acceptance rate (FAR)	0%	0%
Process perception	Security Perception	76%	76%
	Waiting Time Perception	81%	81%
	Security Personnel Friendliness	85%	85%
	Security Personnel Satisfaction	current level	current level

Table 2 – High level requirements

2.3 Functional analysis

2.3.1 Efficiency analysis

2.3.1.1 Introduction

Since 9/11 the walkthrough metal detectors (WTMDs) became more sensitive and occasionally accompanied by other technologies however the detection of dangerous materials is generally performed by body search and visual detection. Random checks and checks based on passenger profiling don't cover the whole amount of passengers. Moreover after the recent events about the failed attack of 25 December 2009 on the Amsterdam-Detroit flight, many airports are installing and requiring the control through the body-scanners that are able to do a complete scan of the entire body of a person. However the checkpoints are already creating bottlenecks at every airport. The queues in front of the checkpoints, the strict measures regarding what is allowed and what is not allowed to be taken inside the secure area are already causing efficiency problems at the airports.

At security check points the passengers have to place all the hand luggage and the removable parts of their clothes to the x-ray machines then walk through the WTMD. After that they are checked visually and sometimes with application of an additional device or they are searched. Meanwhile their luggage and clothes are examined by the x-ray machine operator, and only after this they are allowed to collect their luggage and clothes. Some passengers are requested to clarify some suspicious items detected in their luggage or clothes before being allowed to leave the check point. This whole procedure takes too much time and its efficiency is based on the skills of the security personnel performing it.

Secondary security systems introduced so far provide a high rate of false alarms – usually around 25% of the cases – and were operated separately. This results in that, theoretically, if four different systems are applied then false alarms concern the whole amount of passengers. This on the other hand results in that every passenger has to go through the thorough security procedure to eliminate any suspicion raised. Therefore the application of independently working additional systems with false alarm rate around 25% is creating even bigger pressure on the security procedure.

2.3.1.2 The ATOM system

The ATOM system provides an integrated approach that allows a precise identification of threats by revealing the material, the shape and the location of the hidden item. While previous systems identified the person that might have a hidden item – leaving the identification and location of the actual threat to the security personnel usually by means of body search – the ATOM system shows the material of such item, the shape of it and the location it is hidden at.

The ATOM system provides rather an area coverage than a single point, so it does not create bottlenecks at the passenger flow. As its installation allows that the detection area remains unknown for the passengers, it does not allow easy avoidance of such points. This also means that the secure area begins at the entrance of the airport building instead of behind the security check and the WTMDs. Instead of preventing the dangerous materials and tools from airplanes and airside of the terminal it prevents such items from the entire terminal building, providing thus a wider security area.

Precise identification of the shape, material and location of the dangerous tools and materials provides a possibility for different approach to the security procedures at the security check of the passengers. While previously the security personnel could not possibly know the nature of the threat that an individual passenger might present, so every passenger had to be screened and searched individually at WTMDs thus creating bottlenecks at the passenger flow, the ATOM system provides a different approach. The materials and tools can be identified at the entrance of the terminal and the security personnel can precisely establish the nature of the threat and identify the person that represents that threat, so they can immediately take appropriate measures. In cases being not so obvious, when the suspicion is raised by a particular personnel, the security personnel can obtain clarification at the security check points. Even this clarification is different from the previously applied procedures as the personnel would be informed which person should be checked, what they are looking for and where to find that object even if it is hidden.

The information provided by the ATOM system will allow the security personnel to improve the security procedures. They will not search for “something” that might be there according to their suspicion, but they will search a person knowing that this person has an object that they would like to check. The enhanced information provided by ATOM system will allow airports to increase security introducing new procedures and increasing the coverage of the monitored territory.

Besides that, ATOM system allows “guided search” for the security personnel, so they can focus on suspicious materials and tools instead of performing the usual body search for every passenger. This will reduce the pressure on the security check points and enhance the passenger flow thus reducing the bottlenecks and increasing airport passenger throughput abilities.

The relatively low cost of the ATOM system installation and the integrated approach will allow providing coverage for all relevant areas of the airport. This will increase the overall security of the airport, since using appropriate installation, the security will be able to prevent dangerous materials and tools from the whole terminal area.

The relatively low cost of the ATOM system installation also allows introduction of the system at the smaller airports that have difficulties installing expensive systems. One of the security issues of today’s ATM system is that although the major airports spend considerable amount of money on expensive security systems and introduce strict security check policies, the actual threat may come from smaller airports with less sophisticated security systems and less strict security procedures in form of transit passengers. Introduction of an affordable, yet efficient security system for smaller airports will increase the overall ATM security. On the other hand, full coverage of the transit airports by the ATOM system will increase security even more.

2.3.2 Security analysis

2.3.2.1 Introduction

Airports have always been in the focus of the vicious crimes associated with terrorism (exploding bombs aboard aircraft in flight, ground attacks on aircraft and on ground facilities, using firearms and missiles, hijacking of aircraft) and other ’conventional’ crimes like theft, vandalism and crimes against the person.

Whatever the reason of these criminal act is, there is a need for a persistent readiness in order to avoid the hazardous situations.

2.3.2.2 Protection of the airside and landside

The airside of an airport is usually defined as the movement area of the facility and all adjacent terrain and buildings to which access is controlled. While it is the primary target of the unlawful actions, it has to be protected against unauthorized incursion.

The airside must have an adequate fence in order to obviously define the borders of the restricted area, to inhibit an unlawful entry and to provide controlled access points at gates. Also the access should be restricted to identified personnel.

The airport landside is defined as the area bounded by the points at which passengers and goods enter the airport by all modes and the point on the apron at which the aircraft is serviced and loaded. The airport landside includes access roads and ramps, parking facilities, the terminal curbside, terminal facilities, and the aircraft apron, including the adjacent taxiway.

The protection of the landside is very important in the prevention of unlawful acts. Successful security necessitates that the airside-landside boundary be well defined. The security screening of passengers can be carried out in decentralized (gate screening) and in centralized (before enter to a sterile zone) way. The advantages and disadvantages can be seen in the next table.

Advantages	Disadvantages
Centralized Search	
Favoured by passengers	Passenger segregation in a sterile departure lounge is difficult to achieve
Minimum personnel and equipment needed to process a given number of passengers	Requires staff search
	Control of food and merchandise
Encourages passenger spending in restaurants and duty-free and other shops	Passenger separation (arriving and departing) difficult to achieve
Easier to have policemen on duty in one place	Surveillance of passengers difficult at busy airports
	Only one standard of search is possible, whereas high risk flights may require more thorough search
Gate Search	
The separation and surveillance problem is eliminated	Requires earlier call-forward of passengers
The risk of collusion is minimized	Results in loss of revenue from restaurants, bars, shops, etc.
Allows special measures to be taken on high risk nights	Involves long waiting in crowded gate lounges with no facilities
	Requires more personnel and more equipment to process a given number of passengers
	Creates problems of search team availability of flight schedules go awry-
	Makes a police presence difficult depending on number of gates in use at one time
	Allows passengers to get close to aircraft before search and access to the apron is always possible (emergency exists)
	Enables terrorists to identify specific passengers and lines them up for attack when queuing
	Current gate lounges inadequate for future aircraft

Table 3 – The comparison of centralized and decentralized security operations

The airport security staff must realize that the terrorist organizations might be as well aware of the operating and security procedures as the staff themselves. In the case of a planned attack, it is very possible that these procedures will have been examined. Therefore, from an operational viewpoint, the full extent of the security system should be known to as few people as possible.

2.3.2.3 Security equipment and systems

As all airports providing air passenger transport service feed into the international system, the guarantee of an adequate security system is vital in case of large international and small community airports as well.

The most of the airports have the following, if not all, devices:

1) Security fencing and manned barriers: essential to maintain the integrity of airside-landside
2) Intruder detection: electronic or electromechanical warning system to detect intruders
3) Lighting: Aprons and other airsides need to be lighted to ensure that no illegal activities will happen
4) Metal detection: for the detection of weapons and metallic explosive devices on the passengers or in the luggage
5) Explosive and incendiary device detectors: for the detection of explosive or flammable non-metallic devices
6) Pressure chambers: for the detection of explosives
7) Bunker: For the disposal of bombs and incendiary devices and around any pressure chamber
8) Office security equipment: secure metal cabinets for the protection of security restricted documents, manuals, and plans

2.3.2.4 The ATOM system

The ATOM system could replace more security devices. The people and their luggage have to go through only one security check instead of more, different security inspections (like number 4, 5 and 6 in the previous phase). Moreover for the security check of the suspicious persons or items the common devices and methods (personal scanning, search, manual search of the luggage) can be used as well.

As the ATOM system covers the whole terminal area, all people will be checked who enter the territory of the airport irrespectively of the reason they arrive there. Therefore the staff, the visitors, the people accompanying the travelers will be checked as well.

Since the security check happens not on a specific point of the terminal area, the ATOM system renders more difficult the exploration and the evasion of the security checks for terrorists or people arriving with unlawful intention. Thus also the exploration of the security operations will be harder.

Using the ATOM system an airport could be able to do more efficient security operations with less staff, as the whole territory of the terminal could be in sight from one central security supervision room.

2.3.3 ICT environment analysis

2.3.3.1 Telephony system

A reliable and secure telephone service is essential for every company providing connection with its customers and within the network through direct links:

- Free calls within the telephone network,

- Operates in full service.
- Great variety of phone terminals.
- Features are programmable, depends on phone terminal.

2.3.3.2 Internet

Internet service is a crucial point in airport operations. The internet providing network has to be consistent and secure maintaining fast internet connections:

- Fibre-optic communications network,
- Provides highest available speed,
- Hardware and software firewalls.

2.3.3.3 IP network

Network systems based on globally standardized IP protocol are commonly used in great variety of working environments. Because of improvements in equipment performance and media capabilities, this technology has been developed significantly.

Using this technology by identifying and then selecting the specific capabilities that fit in the computing environment, a powerful and secure IP network can be constructed:

- ASTN network (GMPLS architecture),
- Covers the whole airport area,
- Automatically manages the routing and signalling of a network.

2.3.3.4 Radio system

Airport operations such as flight controlling, apron services and various other ground handling facilities inside and outside of the terminal rely on the modern trunked radio system with high capacity and quality, wide area service and proper in-building coverage:

- Supports 1000+ radios,
- Operates in full service,
- Covers the whole territory of the airport including interiors of operational buildings,
- DAQ 3.4 or higher quality.

2.3.3.5 Common Use Terminal Equipment (CUTE)

The Common Use Terminal Equipment, (CUTE) allows an airport to manage gate and check-in counters and boarding gates in the most efficient way. The CUTE system also enables persistent connection with the appropriate host systems.

2.3.3.6 Flight Information Display System (FIDS)

Flight information is displayed to passengers and airport employees. The sophisticated display techniques of FIDS allow several details of a flight to be displayed in the desired format:

- code shared logos,
- flight numbers,
- arrival/departure of flights,
- multi-lingual flight information (AIS).

2.4 Analysis of the state of art

2.4.1 Airport security systems

2.4.1.1 Introduction

Many recent events show that air transport security still has a demand for reducing the penetrability of the system.

To fill in the gaps of passenger airport security, new regulations (carry-on limitations, screening, removed shoes etc.) have been made. Therefore the security check became an uncomfortable and time-consuming procedure.

The objective of ATOM project is to improve air transport security without holding up regular passenger flow. This can be achieved by introducing innovative surveillance solutions.

2.4.1.2 Current solutions

2.4.1.2.1 Imaging technologies

Numerous imaging technologies can detect metallic and non-metallic materials, even if the object is hidden or covered by multiple layers of clothing. These technologies are already applied in several screening and surveillance applications.

The images generated during screening processes – either passive or active imaging systems have been used – can be post-processed. As the natural radiation of metallic materials and explosives are differentiable from the radiation of the human body, these objects can be recognized on the image.

The following section outlines some of the ways imaging devices could be implemented in an airport environment:

Passive Millimetre-Wave Imaging

The passive millimetre-wave imaging is based on the principle that all objects whose temperature is not below or equal to absolute zero temperature (-273°C or -459°F) emits electromagnetic energy. This energy can be detected and finally converted into an image of the object. Since this technology relies only on the natural radiation of materials and the human body, it does not have any harmful effects on the human health.

Active Millimetre-Wave Imaging

A narrow millimetre-wave energy beam is projected to an object and the reflexive radiation is detected by short-range radar systems. The level of radiation emitted by the radar system is sufficiently low to avoid undesirable impacts on health.

Active x-ray imaging

This imaging technology applies low-energy x-ray radiation to detect metallic and non-metallic objects hidden or covered by multiple layers of clothing. The image is generated from the residual radiation reflected by the object.

Terahertz technology

Terahertz radiation is non-ionizing sub-millimetre microwave radiation. The terahertz radiation wave has the ability to penetrate wood, plastic, ceramics, clothing and several other non-conducting materials so it can be used in surveillance, such as security screening, to uncover concealed weapons on a person, remotely. This is of particular interest because many dangerous or suspicious materials have unique spectral "fingerprints" in the terahertz range. This offers the possibility to combine spectral identification with imaging. Passive detection of Terahertz signatures avoid the bodily privacy concerns of other detection by being targeted to a very specific range of materials and objects.

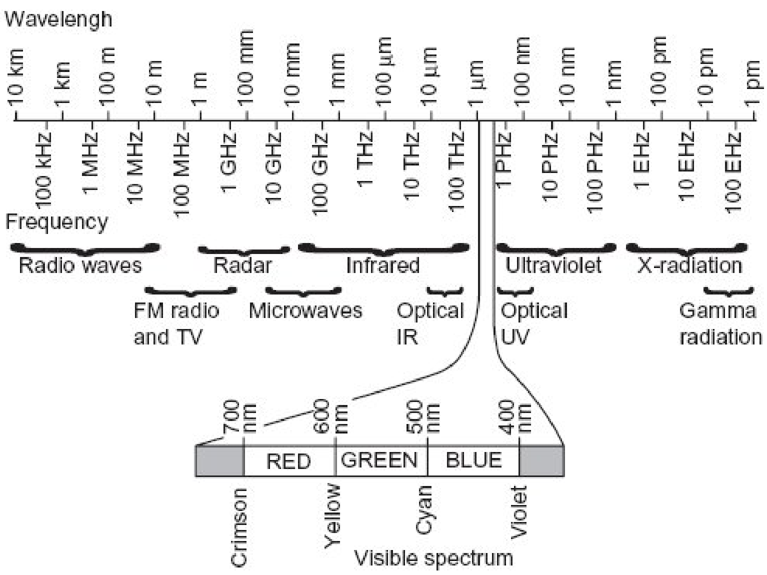

Figure 4 – Electromagnetic Spectrum

The ATOM system would also apply this technology to create a new detection and surveillance system.

2.4.1.2.2 Non-imaging electromagnetic technologies

Non-imaging electromagnetic screening technologies function mainly as metal detectors. The drawback of these systems is that common objects bearing no particular resemblance to weapons, like watches, belt buckles or snaps, can trigger the alarm. Clearing these false alarms consumes time and resources. Furthermore the false alarms can draw away the attention of threat objects and weapons.

Improvements on this technology would make a system more sensitive to weapons by making it more flexible in detecting different metal alloys, and by increasing the perception of the system to locate the suspicious objects more precisely.

2.4.1.2.3 Trace-detection technologies

Trace-detection technologies rely on the chemical detection of the molecules of explosive materials. The sample can be obtained by contact techniques like brushes, hand-held devices or portals where the passenger should walk through. The non-contact option is a closed portal with a ventilation system streaming through air, where the passenger should stay in during the sample collection process.

Current trace-detection technologies are unsuitable to detect metallic objects due to the insufficient sample collection techniques.

2.4.1.3 Examples

Technology	Benefits	Liabilities
Deep Trace	Able to find explosives Red/green light detection	Time consuming, procedure intensive, labour intensive May be defeated by good cleanliness Not able to find metallic weapons
Trace Portals	Able to find explosives Red/green light detection	Reliability issues have been noted Slow - about 15 sec/passengers May be defeated by good cleanliness Not able to find metallic weapons
QR Shoe Scanner	Rapid method for screening shoes Detects small quantities of high power explosives Red/green light detection	Limited breadth of materials Complimentary technology needed Cost/benefit ratio needs to be improved
QR Portal	Able to find small quantities regardless of location and distribution	Limited breadth of materials Background noise elimination may yield a large system Some safety issues to be resolved
Millimetre Wave	Rapid inspection possible Minimal passenger impact Able to locate concealed items No use of ionising radiation	Poor image quality - need a method to resolve anomalies Large systems Blind spots on/in the body
Backscatter X-ray	High quality image	No automatic detection Slow inspection - passenger intrusive Blind spots on/in the body Ionising radiation Privacy vs. detection concerns
Transmission X-ray	High quality image No/minimal blind spots Rapid inspection	Larger dose of ionizing radiation No automatic detection Insensitive to some explosive geometries Physically wide system
Terahertz	Potential for material discrimination Potential stand-off detection	Costly immature Signal affected by water/vapour Operationally unproven

Table 4 – Comparison of the different airport security systems

2.4.2 Technical issues

2.4.2.1 Introduction

In physics, terahertz radiation refers to electromagnetic waves sent at frequencies in the terahertz range. It is also referred to as submillimeter radiation, terahertz waves, terahertz light, T-rays, T-light, T-lux and THz. The term is normally used for the region of the electromagnetic spectrum between 300 gigahertz ($3x10^{11}$ Hz) and 3 terahertz ($3x10^{12}$ Hz).

These waves usually travel in line of sight, like infrared radiation or microwaves. It is a non-ionizing submillimeter microwave radiation and can penetrate a wide variety of non-conducting materials, like clothing, paper, cardboard, wood, masonry, plastic or ceramics. It can also penetrate fog and clouds, but cannot penetrate metal or water.

THz's utility for communication is limited, because the Earth's atmosphere is a strong absorber, so its range radiation is quiet short. In addition, producing and detecting coherent terahertz radiation was technically challenging until the 1990s.

2.4.2.2 Theoretical and technological uses under development

Security:

- As the Terahertz radiation can go through fabrics and plastics, it can be used in surveillance, for example for security screening to detect hidden dangerous materials, objects. Most of the materials have a specific “fingerprint” in the Terahertz range, which allows combining spectral identification with imaging.

Scientific use and imaging:

- Spectroscopy in terahertz radiation could provide novel information in chemistry and biochemistry.
- New methods of THz time-domain spectroscopy (THz TDS) and THZ tomography shows it is possible to perform measurements on, and receive images of samples which are opaque in the visible and near-infrared regions of the spectrum.
- Submillimeter astronomy.
- A primary use of submillimeter waves in physics is the study of condensed matter in high magnetic fields, since at high fields (over about 15 teslas), the Larmor frequencies are in the submillimeter band.
- Terahertz radiation could let art historians see murals hidden beneath coats of plaster or paint in centuries-old building, without harming the artwork.

Medical imaging:

- As THz is a non-ionizing radiation, it won’t damage tissues and DNA, like X-rays. Some frequencies of terahertz radiation can pass through several millimetres of tissues and reflect back and it can also detect differences in water content and density. This allows the effective detection of epithelial cancer in a safer and less painful way, using imaging.
- Some frequencies of terahertz radiation can be used for 3D imaging of teeth and may be more accurate and safer than conventional X-ray imaging in dentistry.

Communication:

- Potential uses exist in high-altitude telecommunications, above altitudes where water vapour causes signal absorption: aircraft to satellite, or satellite to satellite.

Manufacturing:

- Many possible uses of terahertz sensing and imaging are proposed in manufacturing, quality control, and process monitoring. These generally exploit the traits of plastics and cardboard being transparent to terahertz radiation, making it possible to inspect packaged goods.

2.4.2.3 Examples

2.4.2.3.1 Millimeter Wave Imaging for Concealed Weapon Detection and Surveillance at up to 220GHz

Ideally the security sensors have to cover the whole territory of the protected building and its surroundings and have to cope with different environmental conditions in order to detect hidden materials, explosives, weapons, etc. They also have to cover the non-invasive control of men and have to work at a longer distance as standoff detection.

With passive radiometric sensors at 0.1 and 0.2 THz it is possible to detect non-metallic objects and to identify objects like mobile phones or PDAs. Standoff surveillance is also possible, which is very important in regard to suicide bombers.

94 GHz person scanner system

This system is based on a single-channel radiometric receiver mounted on a linear scanning. (Figure 5).

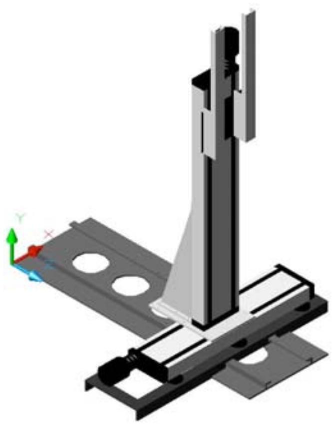

Figure 5 – 94 GHz Person Scanner System

As on Figure 6 it can be seen, not only the detection of the gun is possible, but also of a ceramic weapon, a mobile phone and a PDA.

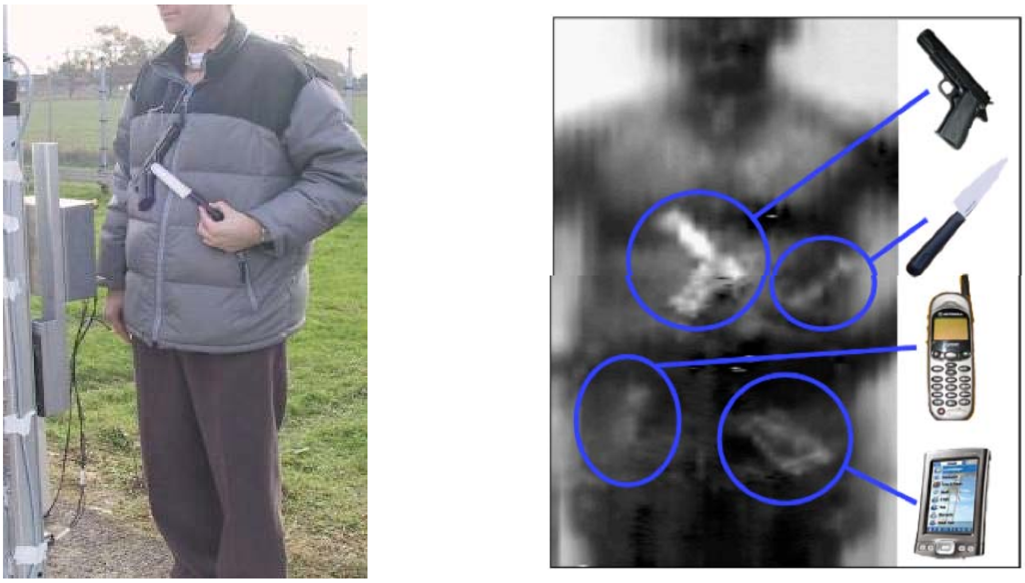

Figure 6 – Detection of different objects

220 GHz standoff at 10m distance

The radiometric system consists of a 2-inch antenna mounted on top of a pedestal. Figure 7 shows the system setup working at 220 GHz.

Figure 7 – The 220 GHz radiometric system

On the following pictures the standoff detection of the system can be seen at 220GHz without (left picture) and with weapon (right picture).

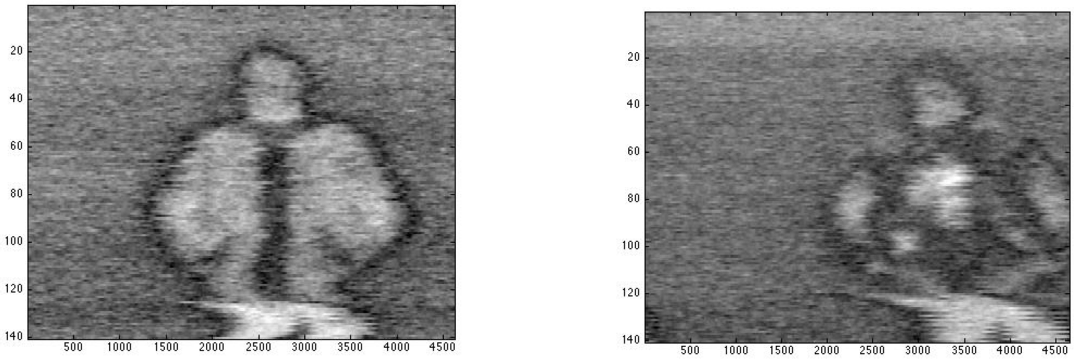

Figure 8 – Standoff detection of the system at 220 GHz

2.4.2.3.2 A 3-D Millimeter Wave Luggage Scanner

This is a light weight, transportable measurements system, which is based upon miniaturized millimeter wave radar modules and operates at W-band. A radar approach is used to achieve sufficient detection capability of hidden objects within a piece of ownerless luggage at a passenger terminal within a short scanning time.

The radar modules (Figure 9) were operated in an FM-CW mode at 94GHz and a bandwidth of 8 GHz.

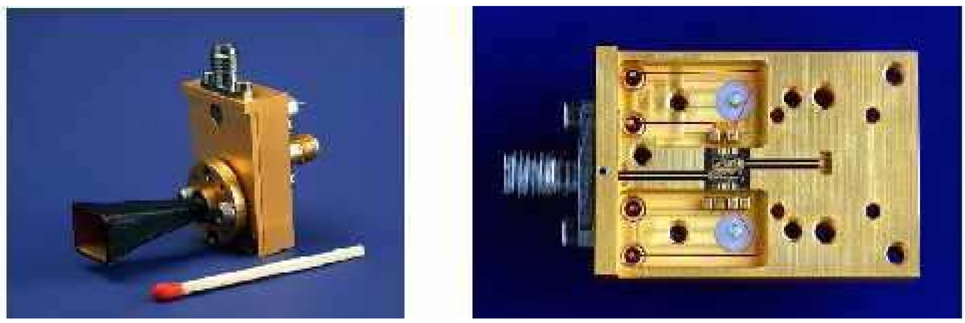

Figure 9 – The radar modules of the 3-D millimeter wave luggage scanner

Figure 10 shows a photo of a suitcase with hidden gun together with a two dimensional representation of the scene deduced from data from a two dimensional scan with respective SAR processing.

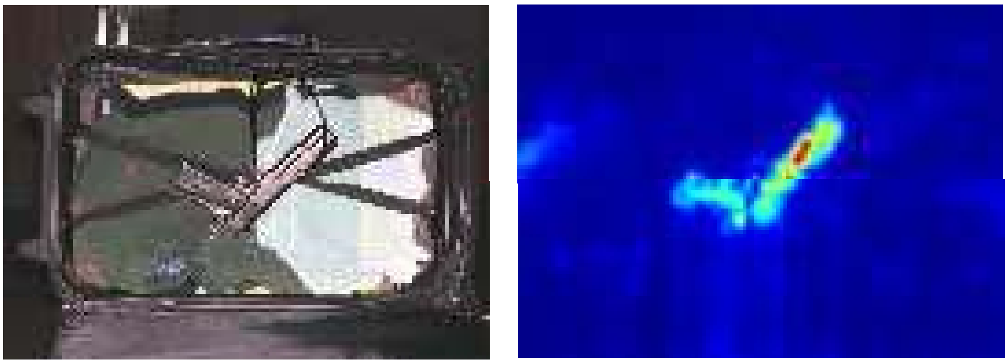

Figure 10 – The picture of a two dimensional scan about a suitcase containing a firearm

2.4.2.3.3 Rapiscan WaveScan 200®

The Rapiscan WaveScan 200® uses passive millimeter wave technology to provide additional levels of flexibility and capability to address challenging personnel screening and object detection requirements. Designed for high throughput inspection, military, Homeland Security and commercial applications, the WaveScan 200 can be used as a stand-off solution or combined with Rapiscan Systems' other screening and detection products to provide a fully integrated checkpoint system.

The Rapiscan WaveScan 200's technology is composed of a real-time Radiometric Scanner that images electromagnetic millimeter wave energy, an integrated full-motion video camera, on-board computer, and sophisticated, intelligent video detection engine. Using the WaveScan 200 detection engine's capability your security screeners will be alerted and can pinpoint concealed objects without intrusive, time-consuming, personnel-intensive and potentially dangerous physical searches, while allowing security screeners to perform "virtual" pat downs from a distance without direct contact. The Rapiscan WaveScan 200 provides an effective means to manage threats before they become harmful incidents.

The system's passive Radiometric Scanner can detect concealed objects by distinguishing between the millimeter wave energy naturally emitted by the human body and the energy of the concealed objects even when they're hidden beneath clothing. It accomplishes this without radiating subjects. Deployed as an stand-off application it will not cause claustrophobia and is a safe and discrete screening solution. Further, the WaveScan 200 millimeter wave sensors do not image anatomical details, thus protecting privacy.

Rapiscan Systems' Graphical User Interface (GUI) is an easy to understand tool - operators can identify hidden objects without confusion or delay. With training, a WaveScan 200 user can identify and locate hidden objects in realtime by observing event icons and detection boxes on a fullmotion video images. Each event's video and passive millimeter wave images are digitally archived for later review, analysis, or evidentiary use. The JPEG images stored are millimeter wave images with no anatomical detail, thereby addressing privacy concerns.

Figure 11 – Rapiscan WaveScan 200®

2.4.2.3.4 SPO-7R™ detectors

High Throughput with High Accuracy

SPO-7R allows an operator to scan a person from a distance of approximately 10 meters without the need for the person to enter a portal, or even to stand still. Scanning takes just a few seconds, making SPO-7R an ideal tool for use in large crowd situations, such as mass transit, border crossings, or special events. It can also be a valuable tool when developing a multi-layer perimeter defense for critical infrastructure, such as embassies, power plants, military bases, and other areas where checkpoint based clearance is required to enter.

Extensive independent testing by a major university laboratory confirms that even with a quick scan, SPO-7R is highly accurate, providing a high probability of detection with a low probability of false alarm.

Concept of Operations

Concept of operations is developed based on the understanding of the threat of concern, methods and operational procedures available in the context of the application. Each security venue will have unique elements to operations that need to be tailored to detection of the specific threats to be intercepted. QinetiQ North America Technology Solutions Group works with customers to ensure all features of operation are understood by operators and training can be customized for the specific application as needed.

SPO-7R is an essential tool in loss prevention and the protection of life and property. Knowing which people have concealed objects and where they are hiding them provides security personnel with a revolutionary tool to screen individuals in real time.

Sample Applications for SPO-7R

- Airport Security: More detailed scanning of passengers as they enter the “snake” line. Allows security personnel to identify persons of interest sooner and re-route them for more careful scrutiny.
- Mass Transit Security: Scan a large number of passengers from a distance without impeding the flow of traffic. Quickly identify those passengers that merit additional security measures.
- High Value Infrastructure Protection (military bases, embassies, nuclear facilities, etc.): Scan people from a distance using go/no-go criteria. Keep people at a distance from the target until they have been cleared. Subjects of interest can be asked to stand in

front of the sensor and turn to expose all sides while they are being asked standard security questions.

- Event Security: Allows scanning of guests and others entering a high-profile event, such as a gathering of political leaders. Easy setup without any infrastructure installation means scanning does not influence the selection of the event's location.
- Border Control: Scan travelers at border checkpoints. Provides for high volume scanning looking for drugs and large amounts of cash.
- Remote Door Entry: Scan entrants prior to allowing them remote access to your embassy or secure facility ensuring large concealed objects are not brought in without investigation.
- Loss Prevention: Managers of warehouse, manufacturing, shipping and retail operations can screen employees for easy-to-conceal high value items. A security team can virtually pat-down employees as they leave the facility without physical contact.
- Crime Prevention: Vehicle-borne SPO-7R units can be deployed in high-crime and school zones at a standoff of 10 to 15 meters.

Figure 12 – SPO-7R™ detector

3 Scenario and threat analysis

3.1 Operational scenarios

3.1.1 Introduction

The aim of this paragraph is to define some different scenarios that will be useful to the validation of the results of the ATOM project. They allows to understand some examples about the operational context in which the system will work.

In these scenarios we consider the terminal area of the airport where people are moving inside. We assume that at certain instant a dangerous object/material, not admitted for security reasons, is introduced inside the considered area. ATOM system shall detect this object/material and track its displacements.

Each scenario involves three different and fundamental entities:

1) Not admitted object/material;
2) mode/means of transport inside the considered area
3) path taken inside the considered area

In the Table 5 some possible classes for the foresaid elements are listed. Each scenario can be defined by selecting a single cell for each column of the table.

Object/material	Scene subject	Path
Guns, Firearms & Weapons	Passenger	Standard
Pointed/edged Weapons & Sharp Objects	Suitcase	Alternative
Blunt instruments	Staff member	Reserved
Explosives and flammable Substances	Group of people	
Chemical and Toxic substances	Other	

Table 5 – Elements involved in the scenarios

According to Regulation (EC) No 622/2003 amended by Regulation (EC) No 68/2004 and Regulation (EC) No 1546/2006 point 4.1.1.1 we consider as:

1) Guns, Firearms & Weapons

Any object capable, or appearing capable, of discharging a projectile or causing injury, including:

- All firearms (Pistols, Revolvers, Rifles, Shotguns etc)
- Replica and imitation firearms
- Component parts of firearms,(excluding telescopic sighting devices & sights)
- Air pistols, rifles and pellet guns
- Signal flare pistols
- Starter pistols
- Toy guns of all types
- Ball Bearing Guns
- Industrial Bolt and Nail Guns
- Cross bows
- Catapults
- Harpoon & Spear Guns
- Animal Humane Killers
- Stun or shocking devices e.g cattle prods, ballistic conducted energy weapons (taser)
- Lighters shaped like a firearm

2) Pointed/edged Weapons & Sharp Objects pointed or bladed

Articles capable of causing injury, including:

- Axes & hatchets
- Arrows & darts
- Crampons
- Harpoons & spears
- Ice axes & ice picks
- Ice skates
- Lockable or flick knives with blades of any length
- Knives, including ceremonial knives, with blades of more than 6 cm, made of metal or any other material strong enough to be used as a potential weapon
- Meat cleavers
- Machetes
- Open razors and blades (excluding safety or disposable razors with blades enclosed in cartridge)
- Sabres, Swords & swordsticks
- Scalpels
- Scissors with blades more than 6 cm in length
- Ski and Walking/Hiking poles
- Throwing stars

- Tradesman's tools that have the potential to be used as a pointed or edged weapon e.g. drills and drill bits, box cutters, utility knives, all saws, screwdrivers, crowbars, hammers, pliers, wrenches/spanners, blow torches
- Sharp objects, of any length, that can be used as a pointed or edged weapon. Syringes for medical use are exempted. (This is an additional regulation applicable in Sweden and many other countries)

3) Pointed/edged Weapons & Sharp Objects pointed or bladed

Any blunt instrument capable of causing injury, including:

- Baseball and softball bats
- Clubs or batons – rigid or flexible - e.g. Billy clubs, blackjacks, night sticks & batons
- Cricket Bats
- Golf Clubs
- Hockey sticks
- Lacrosse sticks
- Kayak and Canoe paddles
- Skateboards
- Billiard, snooker and pool cues
- Fishing rods
- Martial arts equipment e.g. knuckle dusters, clubs, coshes, rice flails, num chucks, kubatons, kubasaunts

4) Explosives and flammable Substances

Any explosive or highly combustible substances which poses a risk to the health of passengers and crew or the security / safety of aircraft or property, including:

- Ammunition
- Blasting caps
- Detonators & fuses
- Explosives and explosive devices
- Replica or imitation explosive material or devices
- Mines & other explosive military stores
- Grenades of all types
- Gas & gas containers e.g. Butane, propane, acetylene, oxygen - in large volume
- Fireworks, flares in any form and other pyrotechnics (including party poppers and toy caps)
- Non safety matches
- Smoke generating canisters or cartridges

- Flammable liquid fuel e.g. Petrol / gasoline, diesel, lighter fluid, alcohol, ethanol
- Aerosol spray paint
- Turpentine & paint thinner
- Alcoholic beverages exceeding 70% by volume (140% proof)

5) Chemical and Toxic substance

Any chemical or toxic substances which poses a risk to the health of passengers and crew or the security / safety of aircraft or property, including:

- Acids and Alkalis e.g. spillable ‘wet’ batteries
- Corrosive or Bleaching Substances - e.g. mercury, chlorine
- Disabling or incapacitating sprays - e.g. mace, pepper spray, tear gas
- Radioactive material - e.g. Medicinal or commercial isotopes
- Poisons
- Infectious or biological hazardous material - e.g. infected blood, bacteria and viruses
- Material capable of spontaneous ignition or combustion
- Fire extinguishers

In practical 3 cases are usually considered of major interest, by synthesizing all the previous:

- metallic firearm (pistol)
- knife
- explosive material

With standard path we mean a path that passengers usually take in order to reach the boarding gate. Instead the alternative path introduces some variant to the usual path (e.g. a person who repeatedly enters in a bar before reaching the boarding gate). The reserved path includes the access to reserved areas, where only staff members are admitted.

In order to support the ATOM system validation, four scenarios of increasing complexity have been identified.

3.1.2 Scenario #1

In the first scenario we consider a man who introduces a dangerous object/material inside the airport terminal, through a standard path. Referring to the Figure 13 below, we assume that the man enters in the area and goes directly to the check-in counter. Stands in the queue among other passengers, then goes directly to the central security filter. Inside the area there are other people that move in the terminal. They are doing normal activity typical of passengers flow. The system detects and tracks suspicious person and detects and tracks unsuspicious persons, avoiding to confuse suspicious and unsuspicious persons in a more complex scene. On the Figure 13 below the unsuspicious people are represented by the blue points while the suspected person is identified by the red point.

When the dangerous person is detected, the system starts the tracking activity in the area surrounding the detection one. This action is taken in order to:

- immediately allow security people to stop and check the suspicious subject
- allow to the other surveillance systems (cameras for instance) to catch the suspicious subject and keep it under control

The scenario can be replicated different times changing the object/material carried inside the airport as follows:

Case 1.1: The man introduces in the terminal a metallic firearm (pistol)

Case 1.2: The man introduces in the terminal a ceramic knife

Case 1.3: The man introduces in the terminal an explosive material

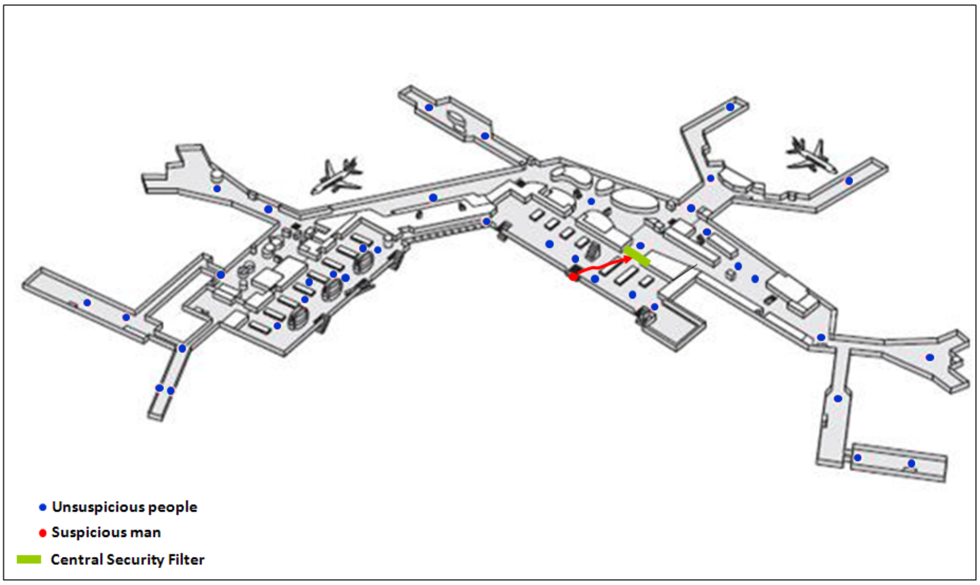

Figure 13 – Scenario #1: A suspicious man enters in the terminal and goes to the central security filter

3.1.3 Scenario #2

A second scenario can be realized considering the arrivals area inside the terminal. In this case the suspected man goes through an alternative path respect to the previous and slightly more complex. He enters in the terminal without crosses the security check. He moves inside the public area and during his path, he enters to a coffee bar. His behaviour is not characteristic of a typical passenger. The man brings with him a metallic firearm. In the area there are other people that move inside represented by the blue points (Figure 14). When the system detects the dangerous material (metallic firearm in this case), it tracks the object in the area surrounding the detection one until the immediately intervention of the security staff. The system must be able to track the suspicious dangerous materials without confusing with the other people and the environment. It also allow to the other surveillance systems (cameras for instance) to catch the suspicious subject and keep it under control. For this scenario, we consider two different cases:

Case 2.1: Within the public area there is a *single* suspicious man with an anomalous behaviour that the system has to detect and track.

Case 2.2: Within the public area there are *two or more* suspicious men with an anomalous behaviour that the system has to detect and track.

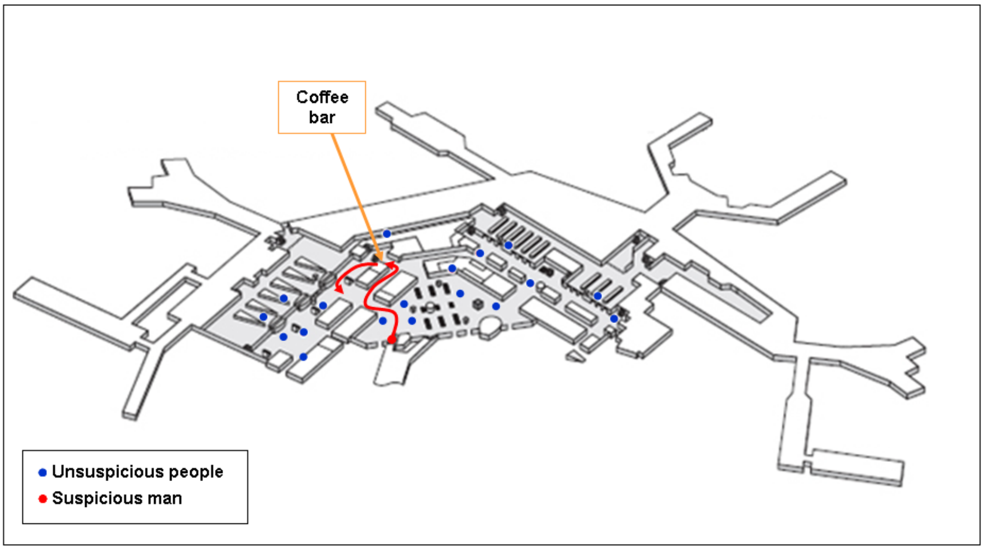

Figure 14 – Scenario #2: A suspicious man enters in the terminal without crossing the security check

3.1.4 Scenario #3

The third scenario takes place in the arrivals area inside the terminal. It can be realized by considering a staff member who works in a restaurant. Referring to the Figure 15 below, the man exits from the restaurant and goes in a large area of the terminal. He brings with him a knife. When he arrives near a corner of the area, he leaves the object. When the system detects the dangerous material, it tracks the object in the area surrounding the detection one until the immediately intervention of the security staff. The system must be able to track the suspicious dangerous materials without confusing with the other people and the environment. It also allow to the other surveillance systems (cameras for instance) to catch the the suspicious subject and keep it under control. For this scenario, we consider to different cases:

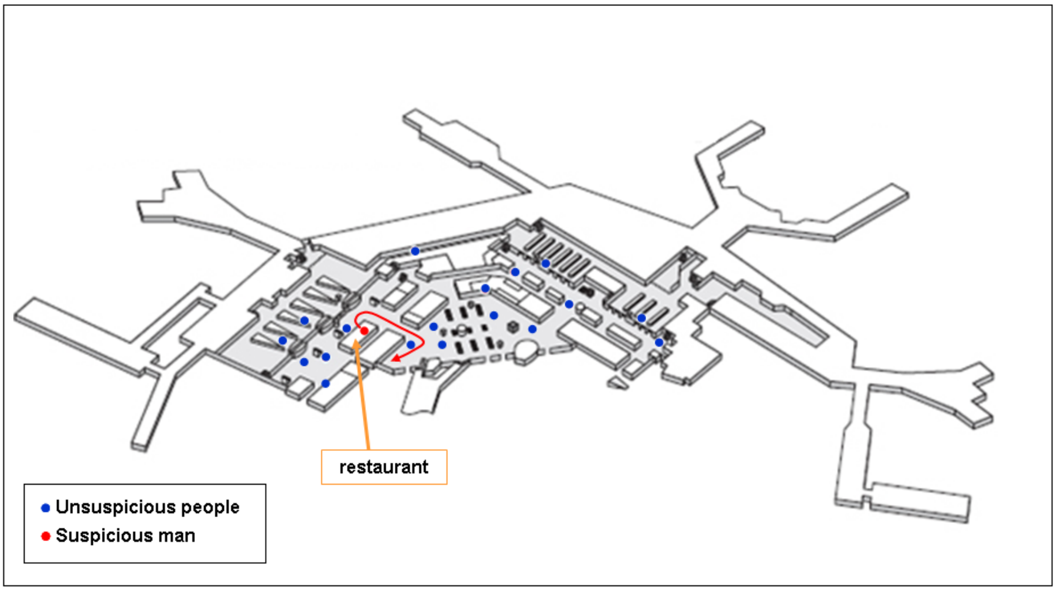

Figure 15 – Scenario #3: A suspicious man exits from a restaurant and leaves a knife in a corner

3.1.5 Scenario #4

At the Schiphol airport (and in all other airport that are members of Schengen agreement) there is not security at the gates for transfer passengers coming from a Schengen country and directed to a Schengen country. In particular Schiphol uses the following concept of security screening about transfer passengers (Figure 16):

- Schengen to Non-Schengen: security at the gate
- Non-Schengen to Schengen: security at the filter between the two areas
- Schengen to Schengen: no security
- Non-Schengen to Non-Schengen: security at the gate

Recent events, such as the failure to attack the flight Amsterdam-Detroit, tell us how important is also the control of transit passengers coming from other countries where controls may be less.

In the fourth scenario, we consider an inbound flight that contains a transfer passenger (coming from Non-Schengen countries) concealing a weapon (for example a metallic firearm) within his personal belongings which has been carried onto the flight from an airport with perhaps less than adequate airport security and who is connecting with a target outbound connecting flight. Such as the previous instance, we consider the Schiphol airport. A possible risk mitigation strategy for our scenario could be a secondary screening of passengers at the gate but ATOM screening could be applied in the transfer area, too. This could be another solution to the problem with less cost. In this case no tracking system is required, but only detection system: suspicious people should be immediately stopped by the staff avoiding that they remain in the sterile area.

From \ To	Schengen	Non-Schengen
Schengen	No security	Gate security
Non-Schengen	Security filter	Gate security

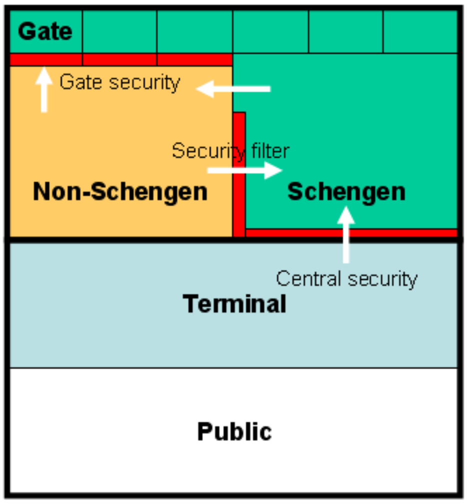

Figure 16 – Transfer passengers security concept at Schiphol airport

4 System requirements and architecture

4.1 ATOM system

The ATOM project intends to study, design and develop the functional prototype of an innovative multi-sensor based system integrating active and passive radar sensors, able to survey wide airport areas without requiring the passengers cooperation by detecting prohibited items and tracking the movements of people carrying these items.

ATOM system will be a non-intrusive but pervasive security system, based on the integration of active and passive radar technology. The non-intrusiveness feature is due to the fact that the ATOM system do not require ad-hoc check points which passengers will have to pass through for being screened.

The scope of the ATOM system is threefold:

- Detection and identification of prohibited items concealed under clothes or inside bags, without interfering with the passengers flows and without requiring passengers to remove their clothes or empty out their bags.
- Tracking the movements of the passengers carrying prohibited items
- Data management and distribution for managing the various information flows and enabling constant tracking of people carrying prohibited items while providing real time feedback to security personnel in the security control center or within the airport area

The approach to be followed foresees two separate and integrated controls:

- One at the terminal accesses equipped with innovative active devices, not interfering with passengers transit and able to detect and identify prohibited items (guns, knifes, non-metallic weapons, explosives, etc.) concealed under clothes or inside bags, without requiring passengers to remove there clothes or empty out their bags.
- The other in the airport before the gate area equipped with new passive RF sensors not interfering with passengers transit and able to track suspicious people.

The integrated controls information will be managed in a secure way within the airport information networks allowing security operators to face threats in the most suitable way, minimizing the risk to other people inside the terminal area.

4.2 Benefits of the new system

4.2.1 Summary of the existing method

The existing method has two parts: one is the walkthrough gate detecting metals while the hand luggage is being X-rayed and the other part is the body search of different intensity.

Figure 17 shows the passenger (and staff) flow at the terminal area:

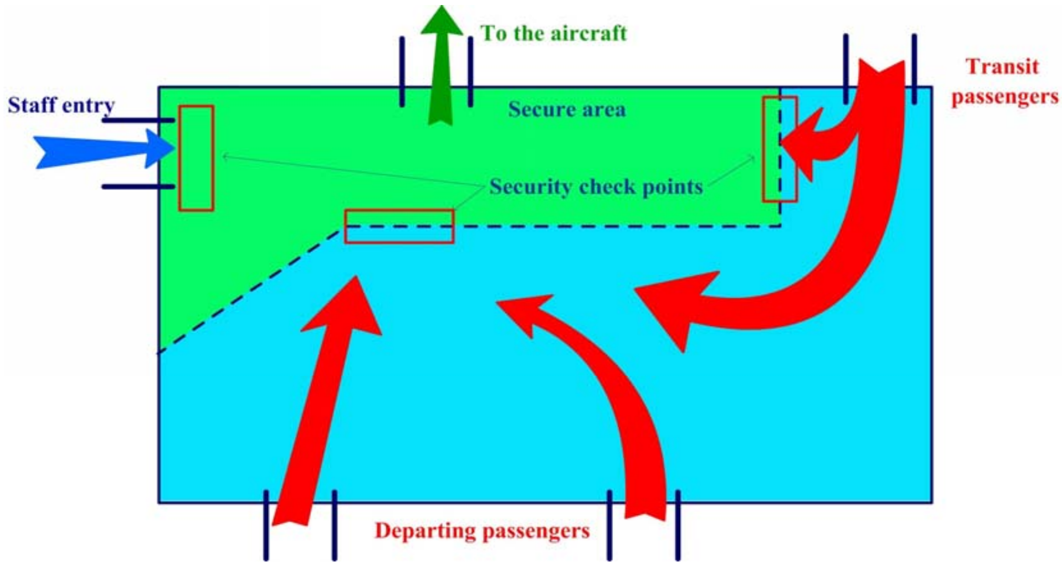

Figure 17 – Passenger flow at the terminal area

The secure area is behind the security check points. All the passengers arriving at the terminal must go through the security check points to enter to the protected area. Although there are CCTV system installed on each terminal, this provides only limited security level. The security check points create bottlenecks at the passenger flow.

In case of transfer passengers the airport security has three options:

- They can assume that these passengers are already in the system, they were checked on the previous airport and they are not representing any threat for the security. This is generally true, but there are airports with different level of security, so this assumption might affect the security level of an airport negatively.
- The other possibility is to install a security check point for the transit passengers too. As the security staff not always has precise information about the number of transit passengers the check point will end up working constantly with staff and tools enough for the average amount of passengers to process. This result that sometimes the staff has nothing to do and sometimes they are overloaded creating the usual bottleneck.
- Some airports consider the transfer passenger as any other passenger and direct them to the usual passenger flow to the usual security check procedure.

In the last two cases the airport maintains its own security level regarding the transfer passengers, but affects the airport's minimum connecting time (MCT) figure.

The airlines using MCT during their scheduling process to calculate the possible connections they can provide to their passengers. If the MCT is too high they are losing some possible connections to other flights and this affects negatively their operations.

Disadvantages of the method are:

- The thorough body search applied to every passenger creates bottlenecks at the already overcrowded terminals
- The WTMDs can only detect presence of metal objects. There is no indication regarding their location of shape, so the body search is applied again.
- Application of additional systems that have high level of false alarms (around 20-25%) creates additional workload to the security personnel

- Even if no metal is detected, to prevent dangerous tool and explosives there is a need for additional body search that's effectiveness again depends on the staff training.
- The always changing list of items allowed to the security area and of course to the aircraft confuses the passengers and creates uncomfortable feeling
- The X-ray equipment has to be monitored constantly (no automatic detection) and effectiveness depends on the operators' training
- Requires considerable manpower
- Slow
- Relative security is provided only beyond the checkpoint

4.2.2 Advantages of the new system incorporation

Figure 18 the passenger (and staff) flow at the terminal area using ATOM system.

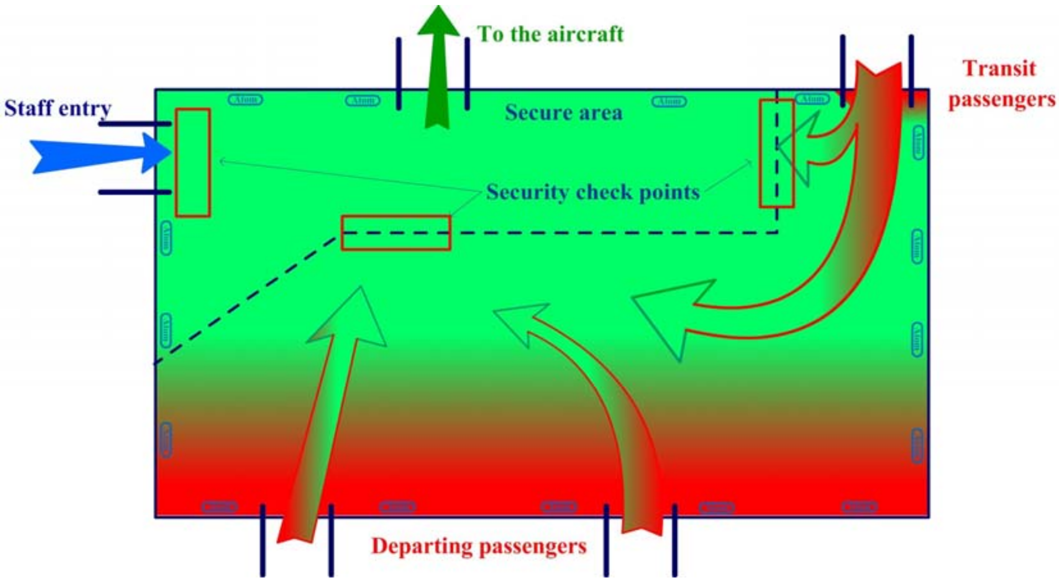

Figure 18 – Passenger flow at the terminal area using ATOM system

The implementation of the ATOM system allows minimizing the negative impact to the passenger flow by the security check points. The passengers entering the terminal building are instantly being checked regarding the dangerous material and tools. The security check points are only filtering the suspicious cases creating less negative affection to the passenger flow of both transit and regular passengers.

The advantages of the ATOM system:

- The ATOM system would provide coverage for the entire terminal building.
- The ATOM system provides secure recognition of dangerous materials and tools. The system not only indicates their presence at the terminal building, but pinpoints the person carrying them. The security personnel have the possibility to take appropriate measures as soon as the threat is identified. Every other suspicious case can be processed at the checkpoints.
- The random body search still can be applied, but the whole security check procedure can be based on the precise data provided by ATOM system. This means that thorough body search procedure should apply only to the persons carrying objects that need further examination. This would reduce the workload on the security personnel

yet makes the procedure more precise and fast. The security staff would know in advance what they are looking for and where to find it.

- The fast and reliable security procedure will increase security level yet reduces the bottlenecks at the terminal buildings.
- The ATOM system allows the reliable detection of dangerous materials and tools on the territory of the whole terminal, so it covers the transit passengers coming from flights departed at less secure airports. This way it has a positive effect on the whole ATM system's security level.
- The ATOM system effects the regulations regarding the items allowed on board of the aircraft as in present time usually there is no way to tell what a particular object contains, but the ATOM system would provide a precise identification. This would have positive effect on the comfort of the passengers.
- The checkpoint would process an already pre-processed passenger flow concentrating on suspicious elements of it with the ability to perform targeted search. This would enhance the efficiency of the security check and speed up the whole process.
- The automated detection of presence of dangerous materials on the terminal area would prevent
  - Dependency on staff training
  - And raise the risk of detection for persons intending to perform unlawful act.

4.3 ATOM system analysis

4.3.1 ATOM system requirements

The purpose of the ATOM system is to achieve the performance required by the final users in term of detections of threat and false alarms. Particularly, starting from the airport structure, the best setup of the ATOM system will be defined in order to assure the best achievable performance. The airport structure is the key point in the ATOM system because the deployment of sensors of the detection sub-system depends on the airport accesses.

The development of advanced surveillance systems, as well as their integration with currently used surveillance systems in order to obtain an integrated security system having enhanced capabilities of detection and tracking of dangerous tools and materials will be the content of the research activities foreseen in the ATOM project.

Particularly, the ATOM system foresees two control levels, as illustrated in Figure 19

- A first control at the airport entrance, where an automatic detection system controls all the people (passengers and others) that coming in the airport and alarms the security operators when a suspicious person is detected. The tracking system allows to the security operators to track the suspicious people and analyze his behaviours in order to maintain the security in airport.
- The second control is placed at the gate entrance, where the detection system controls all the passengers. After this second control the suspicious people are subjected at the regular screening. After this second control the clean and suspicious people can not get in contact in order to not contaminate clean people.

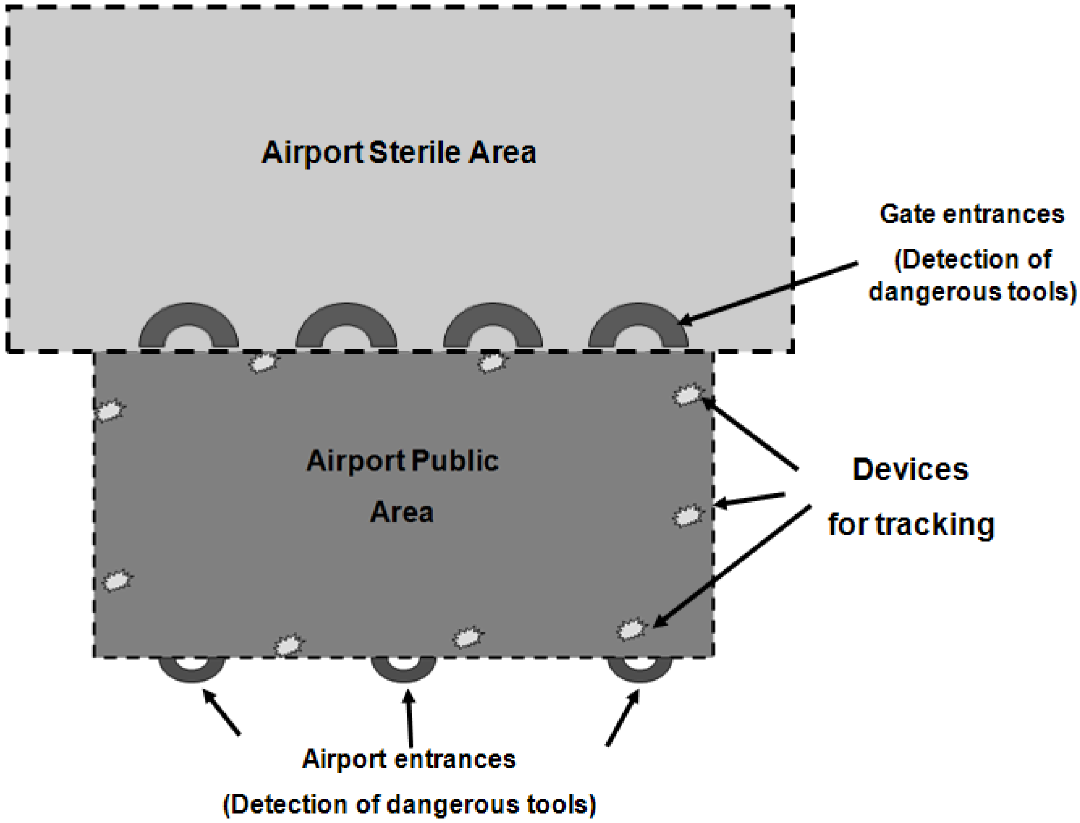

Figure 19 – Distributed controls in the ATOM system

The diagram of Figure 20 shows the three main blocks of the system subject of the proposed research project: ATOM system will integrate innovative detection system and innovative tracking systems, as well as an innovative data management and distribution unit.

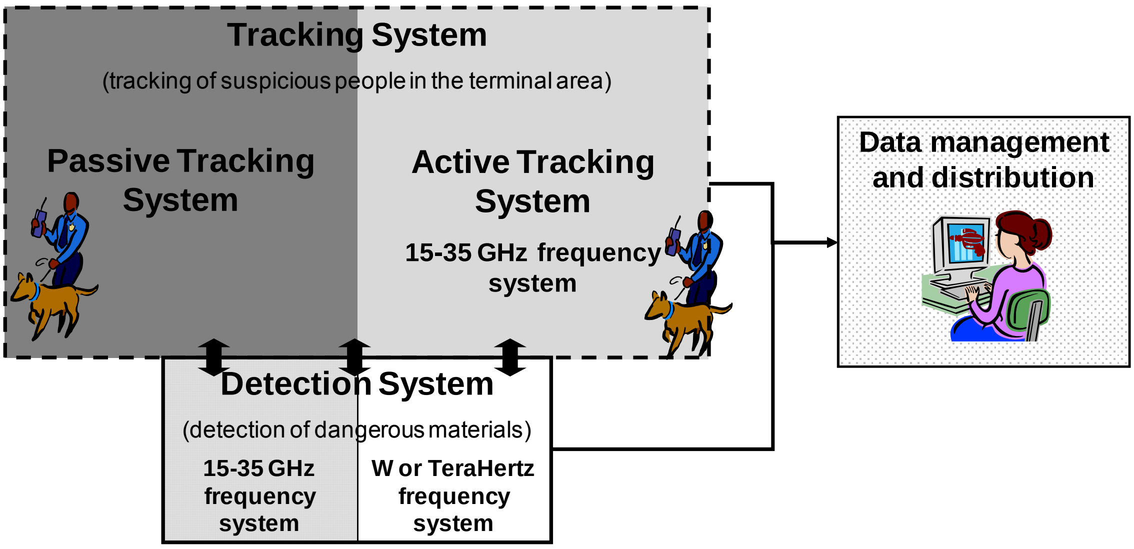

Figure 20 – Main blocks of the ATOM system

4.3.2 ATOM system operational requirements

The overall objective of ATOM project is to contribute to improve the security in the airport area and on board A/C by:

- Detecting and identifying, without interfering neither with the normal passengers flows, nor with the normal airport operations, the presence of hazardous materials or tools, concealed (under clothes or inside bags) by ill-intentioned people circulating inside airports and that could be used for delivering attacks either against the airports themselves or against A/C;
- tracking the movements of those threatening people concealing those forbidden items, so that they can easily be localized by security operators.

In order to achieve this general objective, ATOM project intends to study, design and develop the functional prototype of an innovative system (hereinafter also referred to as ATOM system) based on a multi-sensor approach that integrates active and passive radar sensors, able to survey wide airport areas without requiring the passengers cooperation as well as to detect hazardous materials/tools and to track threatening people; this way, the ATOM system will improve the security level not only in the gate area, but at a preliminary stage, also in the Terminal area of the airport.

The technical approach that will be followed foresees two separated and integrated controls (Figure 21):

1) One at the airport access, equipped with devices not interfering with passengers transit and able to detect and identify tools (such as guns, knives, non-metallic weapons, explosives, etc…) concealed under clothes or inside bags, without requiring passengers to remove their clothes or to empty out their bags.
2) The other in the airport before the gate area, equipped with passive RF sensors not interfering with passengers transit and able to detect and track suspicious people.

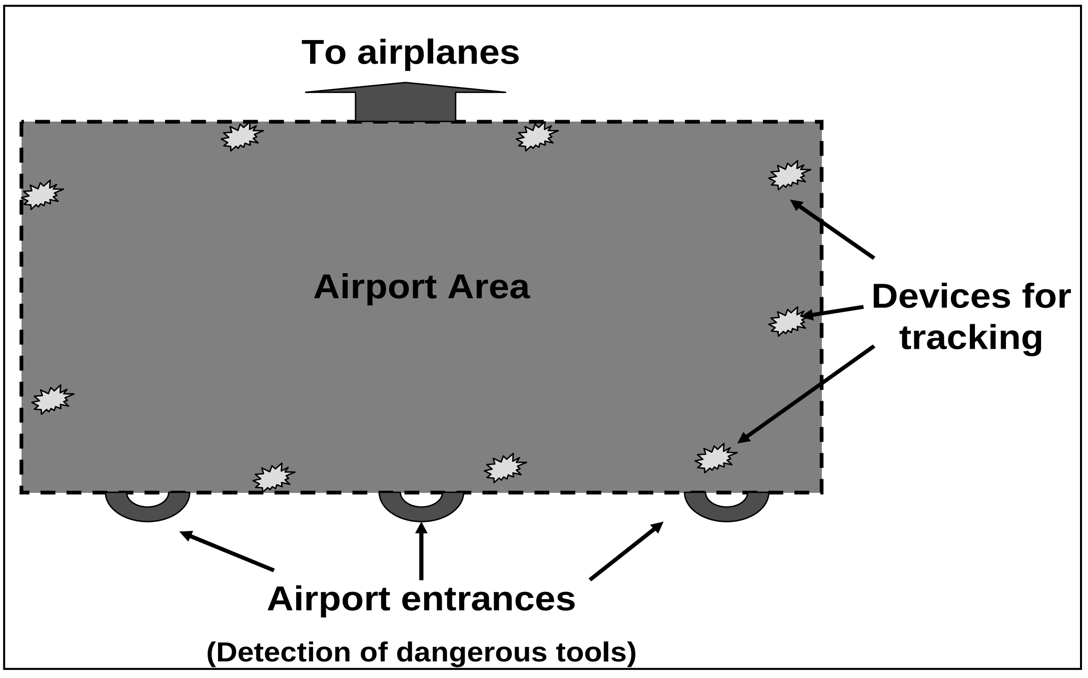

Figure 21 – Distribution of the detection and tracking sensors of ATOM system in the airport area

Two types of sensor are foreseen for the different controls:

1) Imaging sensor able to detect suspicious people concealing dangerous tools:

- Aim is to study and develop expensive high-complexity equipments in the W-band[1] of the microwave part of the e.m. spectrum or at terahertz frequency.
- Laboratory experiments in order to test the feasibility of less expensive medium- complexity approaches in the 15÷35GHz frequency range[2].

2) Tracking of suspicious people within the terminal area:

- Active tracking of suspicious people. Laboratory experiments in order to test the feasibility of less expensive medium - complexity approaches in the 15÷35GHz frequency range.
- Passive tracking sensor opportunities based on GSM or WiFi transmissions will be analyzed in order to track suspicious people within the Terminal area.

Measurement setup of the millimetre wave imaging concept. As indicated in the previous items, an accurate imaging of single passengers requires a regular (even a predictable movement) of the persons. Furthermore, they should be forced to enter the imaging area separately to avoid shadowing effects and unscanned body areas. It should be discussed how this could be achieved with a minimal influence of the passenger flow. The imaging sensor will operate at frequencies about 94 GHz, corresponding to a wavelength of about 1 mm. The signal processing is carried out by using the SAR (synthetic aperture radar) principle which presumes knowledge of the radar sensor position and the target (passenger) position with an accuracy corresponding to the wave length. This implies that during the measurement the person should stand still or should conduct a regular movement (like on an escalator or a moving walkway). Otherwise, the radar image gets smeared or completely unfeasible for threat detection.

The concept of rotating platforms with multiple transmitters / receivers. According to the description of work, we propose as a test setup the construction of two rotating platforms (over and under the person under test) on which at least one transmitter and 2, 3 or more receivers are fastened. One platform could be in the ground with a radar transparent cover, the other one could be mounted on the ceiling. The height difference between the platforms has for a 2m tall person 4m due to the restricted unambiguity in bistatic radar systems.

Project partner Fraunhofer will develop a W band radar with a centre frequency of about 94 GHz and a bandwidth of 3 GHz to 6 GHz depending on the hardware components which are available on the market with a moderate delivery time. The required mechanical and electrical steering system and the electronic for the digitization of the received signals will be developed by Fraunhofer, too.

The fusion of the two imaging systems is one main part of the research activities which is conducted in the project. It can be estimated that the two systems give a large benefit regarding the identification of different items, especially the 15 to 35 GHz system due to the bandwidth of 20 GHz. Furthermore, a higher detection rate is expected using two systems operating at different frequencies and with different setups of the radar modules. The advantage is that if one system is not able to detect a suspicious item reliable (maybe due to an unfortunate orientation of the object such that the back scattered wave does not reach the receiver), the other system can do it due to different geometries.

By exploiting sources of illumination widely available in the airport environment, a tracking system based on Passive Radar networks may allow a wide space coverage, but it also represents a challenge from the scientific point of view, as Passive Radar technology is still at an experimental stage and it is not yet considered fully operational inside surveillance systems (mainly because its performances have not yet been completely evaluated).

[1] The W-band includes frequencies in the range [75GHz, 111GHz], which have wavelength in the range [2.7mm, 4mm]

[2] The frequency range 15÷35GHz falls within the so called K_a-band of the microwave part of the e.m. spectrum

Also the use of high-frequency (and high-energy) active radars for the detection of concealed weapons and explosives represents a scientific innovation of the ATOM project, as, until recently, researchers have had great difficulty harnessing the potential of the high-energy region of the e.m. spectrum, mainly for the lack of the infrastructure needed to move high-energy radar technology from the laboratory to the field.

Activities will be carried out for evaluating the best results by making trade-off studies between exploiting all the possible solutions for the dangerous tools detection, identification and tracking with the main objective to provide an integrated security system able to control the whole airport area and to provide the security authority with advanced information on location of dangerous tools.

The different solutions, particularly regarding the detection and identification of the dangerous tools, will be compared taking into account the technical issues (type of identifiable materials, accuracy of identification, etc) as well as the complexity in the development and installation of the devices.

A series of similar sensor’s array strategically deployed, for instance in all the access areas of the terminal could realize a non-interfering detection systems providing security control in all the terminal area. All the sensor’s array will be networked and provide their output to a centralized control station where specific detections and tracking algorithms and applications will present hazardous situations to the security operators. The project will consider the possibility to transmit such information on a proprietary or on a general purpose LAN, including the possibility to use advanced transmission features.

In order to achieve the operational requirements, the ATOM system will provide to the security operators the data on prohibited items and people that carrying out them. The achievement of this result depends on the characteristics of each sub-system and on the capability to fuse and integrate all the available data. Besides, an accurate analysis of the available data should reduce as much as possible the additional controls of the security operators.

An accurate analysis of the airport structure and the possibility to create a bind crossing should reduce the number of detection sensors without impact on the system capability.

The capability of tracking of the dangerous people depends on the type and number of sensors of the tracking sub-system and on the performance of the data fusion system.

4.4 ATOM system architecture

4.4.1 General overview

In this section the ATOM system architecture will be described. The overall architecture can be divided into two main blocks (see Figure 22). In the first one, referred to the terminal area, we can see three different sub-systems: Detection System I, tracking system and data management system.

In the Gate area (second block), no tracking system is required, but only detection system: suspicious people should be immediately stopped by the staff avoiding that they remain in the sterile area.

Detection system is connected to data management block. Via the communication network (see next figures), data management sends information to both the tracking system and the security operator. The tracking system provides the updated track to the Decision support system (DSS) in the data management block. Here the system can detect automatically the dangerous person or send the information to the security operator that decides whether to alert the security staff or leave free access to the observed person.

In the following sections each sub-system is described separately.

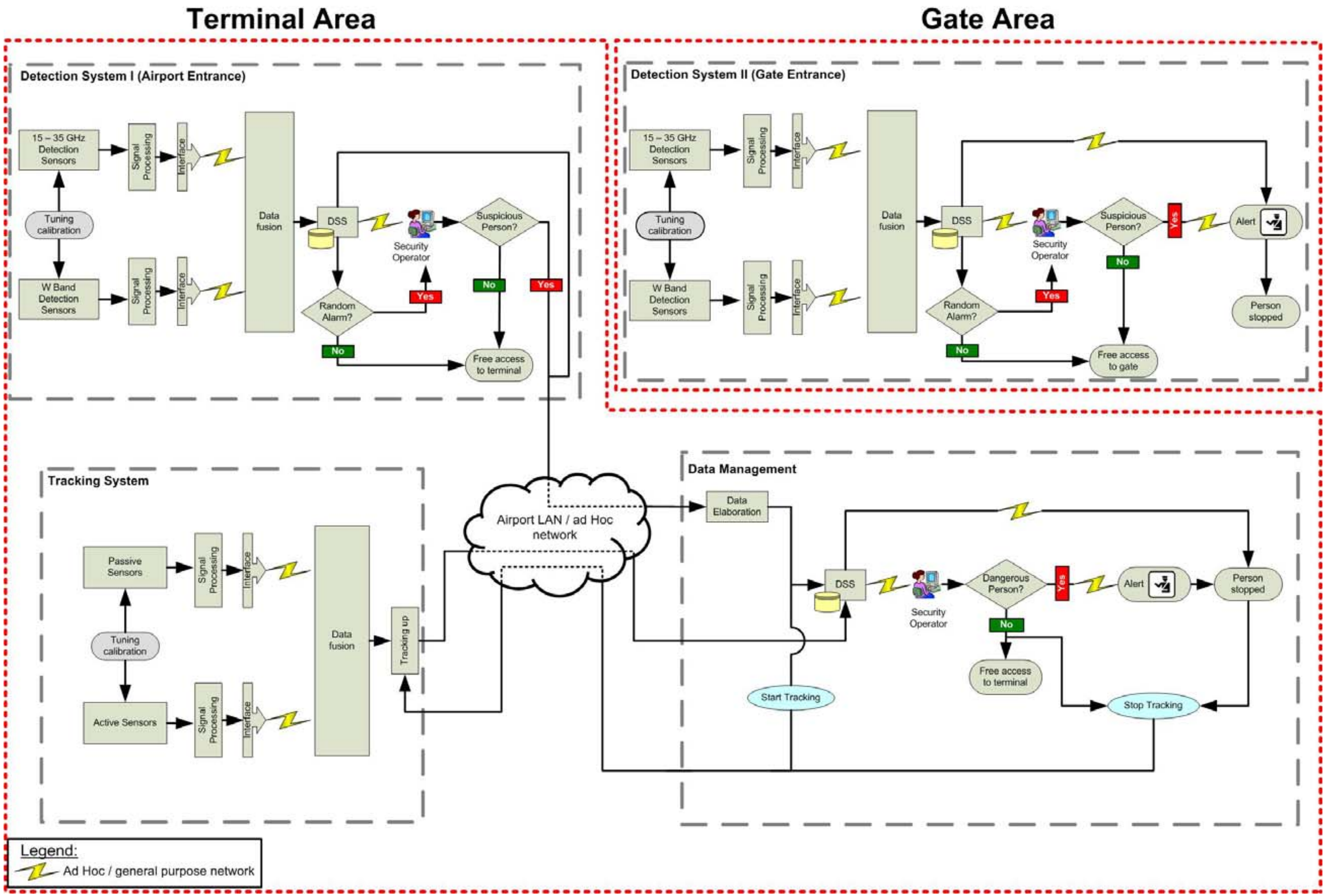

Figure 22 – ATOM Architecture

4.4.2 Detection system

Two detection systems are planned in ATOM. Both are composed of 15-35 GHz and W band detection sensors. The first is located in the airport entrance, the second in the gate entrance (Figure 22). Considering first the terminal area, the 15-35 GHz and W band detection sensors, after signal processing, send information to the data fusion which provides a single output which enters to the Decision Support System (DSS). The DSS, through an internal database, can take three different decisions. If the system detects a suspicious person, and it is certain with high probability of having detected a dangerous object/material that should not be introduced in the terminal, the data are sent directly to the management block, via the network. If the DSS doesn't detect an anomalous situation (in the most cases) it allows free access to airport terminal for passengers. To further increase the level of security is provided with a certain probability (random alarm) that some of the people / objects deemed clean by the DSS are also controlled by the security operator, even if the system had not detected any threat. In doubtful cases, i.e. when a suspicious object is detected but not well classified by DSS, a security operator can manually take the decision by observing the scene through a monitor, including all supporting information as possible that the DSS can give. To allow the DSS to be able to take a decision, is very important to establish a threshold. In fact, its value determines the performance of the overall system, in terms of false rejection rate (the passengers are wrongly suspected by the security system of carrying prohibited items) and false acceptance rate (the passengers are wrongly cleared by the security system). The threshold must be chosen so as to optimize the system and to achieve the desired performance.

However in output of the detection system I (terminal area) a decision is taken. In case of suspicious person the data is sent to the management block, via the communication network. (Figure 23)

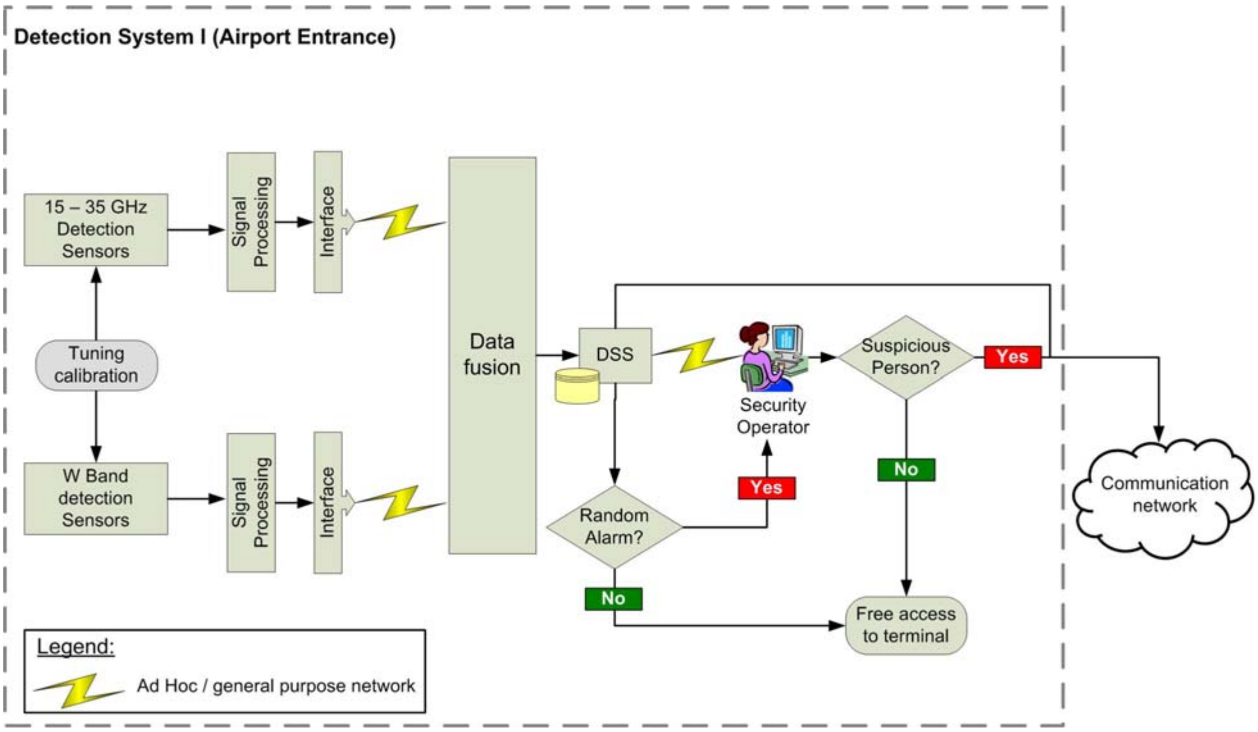

Figure 23 – ATOM Architecture: Detection system I (Airport entrance)

The detection system II, located in the gate area, is similar to the first one, previously analyzed (Figure 24). Sensors, signal processing and data fusion are exactly like the case of the terminal area. Some differences are due to the higher level of security required. Anything suspicious in the gate area has to be stopped and identified as soon as possible. This requires a more stringent threshold in the DSS. When the system detects (automatically or by the security operator) a suspicious person, the security staff is alerted immediately and he shall stop the threat.

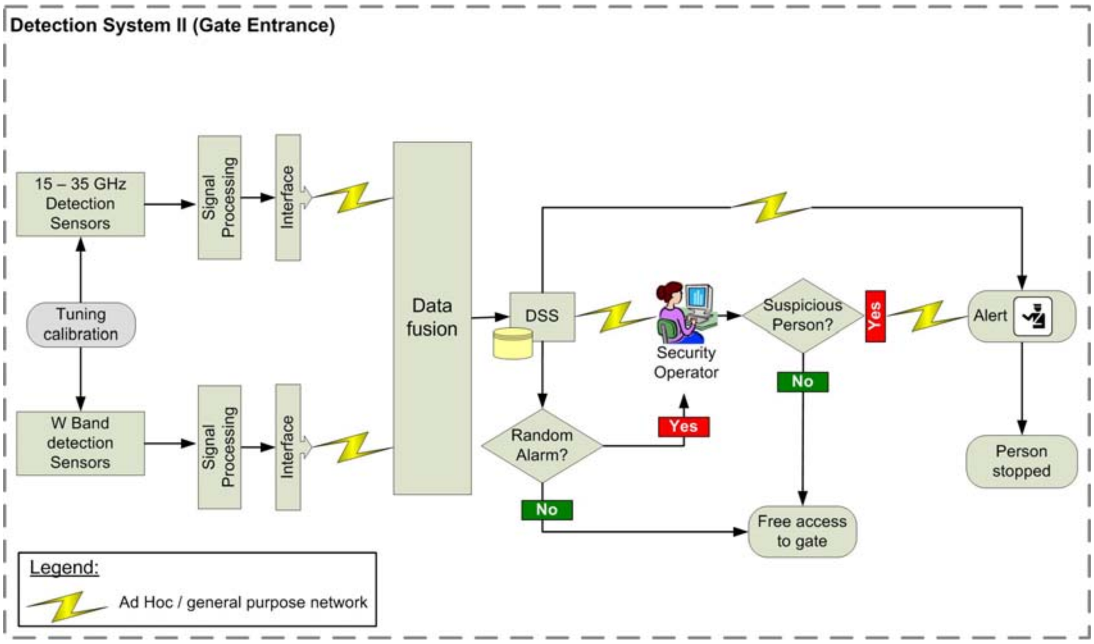

Figure 24 – ATOM Architecture: detection system II (Gate entrance)

4.4.3 Tracking system

The tracking system block (Figure 25) is composed of passive and active sensors. Data fusion block is required to combine the different kind of data of the sensors. Once the data fusion is done the tracking block provides tracking of the suspicious persons. The tracking system is activated only when the management block requires it, i.e. when it sees a possible threat in the terminal through the detection system. The initialization process comes through the communication network. The output of tracking block is the updated track of the person that is sent to the management block via the communication network. The system stops tracking when the management block requires it, i.e. when the threat has been stopped

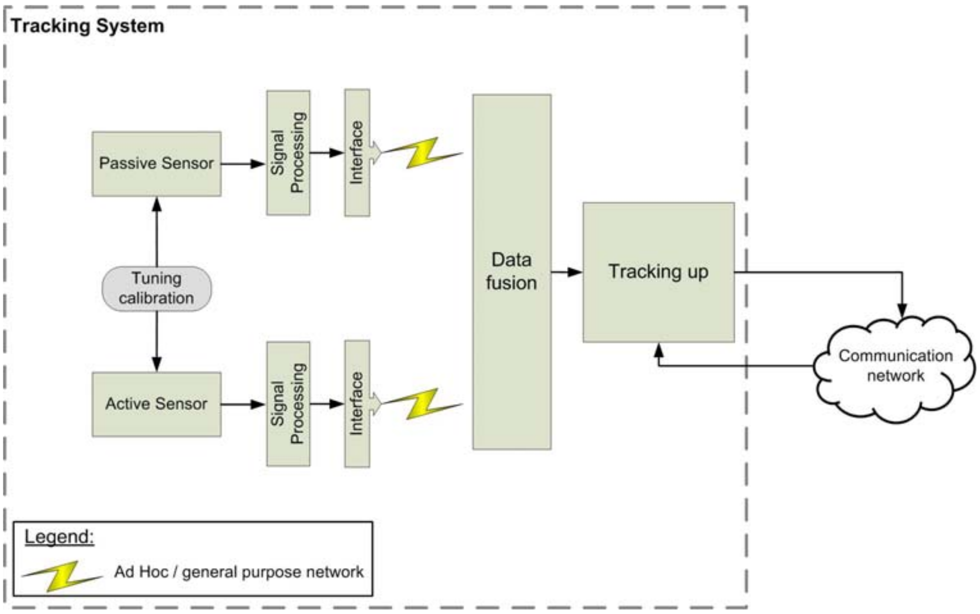

Figure 25 – ATOM Architecture: tracking system block

4.4.4 Data management

Data management block is the core of the whole system. Here arrive the data coming from the detection system I (terminal area) when a threat has been detected. Through the communication network, the data go to the elaboration block which provides to start tracking and to communicate the initial coordinates of the target. Data coming from tracking block, with those from the detection block, go to the DSS. Through the use of a database, if the DSS is able automatically to detect the threat, the security staff is alerted immediately and he shall stop the threat. In doubtful cases, i.e. when a suspicious object is detected but not well classified by the DSS, a security operator can manually take the decision by observing the scene through a monitor, including all supporting information as possible that the DSS can give. The security operator can decide if allows free access to airport terminal for the person observed or not. However, when the security operator determines that there is not any threat or when the suspicious person is stopped, the system results in stop tracking, sending the request to the tracking block.

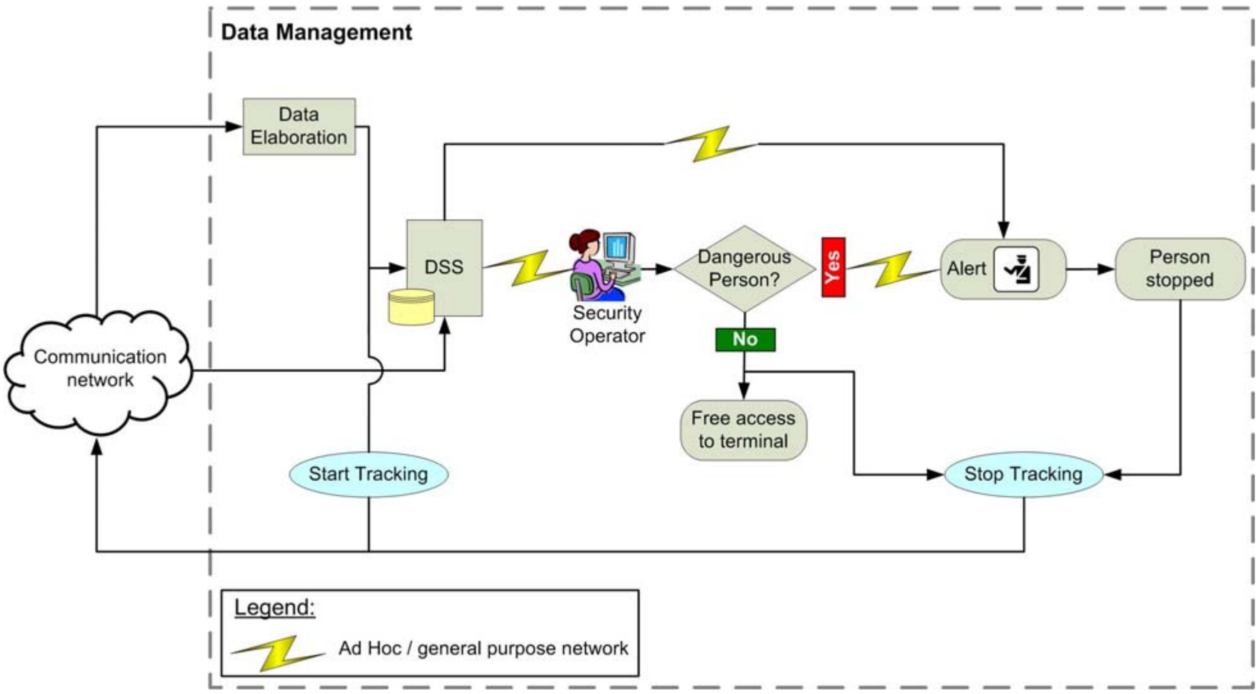

Figure 26 – ATOM Architecture: data management block

4.5 Sub-systems requirement analysis

In this section we want to describe all the sub-systems that compose ATOM. In particular we will start with the Ultra-Wideband Microwave Radar (15–35 GHz frequency range). Then we will describe the W band- terahertz detection sub-system, the passive tracking radar and the active tracking radar. The paragraph ends with the data fusion and management sub-system description and some network infrastructure issues. Our aim is to find the match points between high level and sub-systems requirements.

4.5.1 Ultra-Wideband Microwave Radar in the 15–35 GHz frequency range sub system

4.5.1.1 Introduction

Active Ultra-wideband (UWB) microwave imaging provides 3-D pictures using microwave energy. The utilized microwave spectrum is able to pass through barriers such as clothing and plastic without being a health hazard. Therefore, weapons such as gun, knife or explosives hidden under cloth or inside bags can be seen by the 'radio camera' and further identified by pattern recognition computers. The commuters and their carried belongings to be screened are illuminated by microwave transmitters and the reflected or scattered field are intercepted and collected by receiving antennas. The system processes the received echoes in the beamforming process transforming the observed wave field into a three-dimensional image. This beamforming process is analogous to the function of lens in a camera. Because of the wide bandwidth employed, the technology allows resolving capability in three dimensions from a planar array without scanning around the target. The microwave transmitter serves as the role that the sun does in optical photography, therefore, avoiding limitation in possible indoor or night-time scenarios. By applying a 2-D planar array, the whole screening process can be performed in real-time, which allows detection of potential threats without disrupting the passenger flow and normal airport operations.

Comparing with narrowband phase array or millimeter-wave imaging radar, the 15-35GHz wideband sensor system is characterized by several uniquely attractive features:

- Low-power emission and consumption, less impact on other RF systems in the airport
- Immunity to interference from narrow band RF systems
- Multipath immunity due to wide bandwidth
- High down-range resolution, capable of precise positioning due to fine time resolution
- Allowing use of sparse array with less antenna elements that leads to less data acquisition time, less signal processing complexity, and lighter device
- Low-complexity transceiver architecture

The capabilities of the 15-35 GHz system are described in the following in terms of achievable resolution, requirements for data acquisition, as well as detection and recognition.

4.5.1.2 Achievable Resolution

The resolution of wideband radar in the down-range direction is purely determined by its operational bandwidth. With 15-35 GHz, the achievable down-range resolution, δ_r, is estimated by

$$\delta_r = \frac{c}{2B} = \frac{c}{2*20e^9} = 7.5\ mm \qquad (1)$$

where $B = 20GHz$ is the operational bandwidth, and c represents the propagation speed of the electromagnetic field in free-space. Because down-range resolution is range-independent, it provides a basis for precise positioning and tracking capabilities.

One of the major challenges of microwave imaging radar is the cross-range resolution, which has been shown to be inversely proportional to the center operational frequency

$$\delta_{cr} = \frac{\lambda_c \cdot R}{L} \quad (2)$$

where $\lambda_c = c / 25GHz = 12mm$ denotes the wavelength at center frequency of the chosen frequency band, R is the range distance of the target, and L represents the size of the array aperture. It is known that bandwidth plays little role in term of resolution in the cross-range.

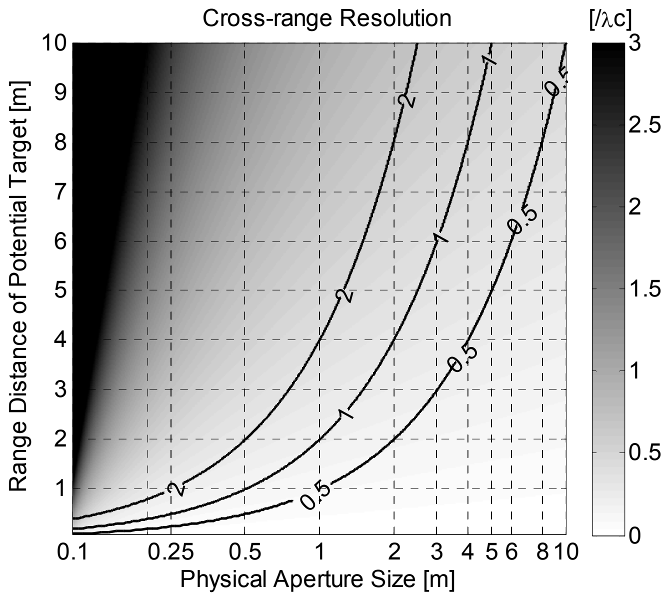

Figure 27 – Cross-range resolution of two-way array under variant physical aperture size and range of target

In order to obtain a level of angular resolution comparable to the utilized microwave wavelength, the size of the array aperture must be similar to the distance of the potential target. The obtainable cross-range resolution in terms of wavelength at center frequency for variant device size and target range is illustrated by Figure 27. For the situation where the passenger is within 1 meter range from the array aperture, the dimension of the device can be relative small and be controlled within 0.5m wide. In an open space, such as the public area within the airport entrance, the potential distance of target can be much greater as in the range from 2 to 10 meters. Correspondingly, the width of the device has to be enlarged to be around 5 m. The sensor system can be placed on the sidewalls or in the middle of pass ways in order to pick up potential threats in the passengers. In both scenarios, planar 2-D array is assumed in order to achieve the project objective of not interfering with normal passengers flows and with normal airport operation.

4.5.1.3 Imaging quality and requirements for data acquisition

The major challenge in the development of planar array is the number of antenna elements required to effectively steer and focus the beam. Under monochromatic condition, element spacing within the array must be less than one-half of a wavelength in order to prevent unwanted grating lobes. It is well recognized that high level grating lobes can severely reduce the dynamic range and contrast available for imaging. However, satisfying the half-wavelength criterion in practice leads to an extremely dense array for a moderate aperture size and resolution. For example, to achieve 1 cm resolution at 1 m range, the array aperture must be a least 100 times of a wavelength along both azimuth and elevation plane. In order to control its beam steering capability, the 2-D array will require $201 \times 201 = 40,401$ elements. Unfortunately, fabrication of such a dense array and its associated beamforming electronics is still unrealistic using existing microwave technology.

In contrast to its effect on cross-range resolution, bandwidth plays an important role on controlling the beam pattern. Due to ultra-wideband signal transmitted, signals from far fewer elements form the grating lobe than the main lobe which leads to amplitude lowering of grating lobes. The ideal side lobe level (ISL) of a UWB array is defined as

$$ISL = 20\log_{10}\frac{1}{\mathrm{N}} \qquad (3)$$

where N is the number of elements within a 1-D linear array. It indicates the minimum artefact level in the resulting image and can be used as starting point to determine the minimum number of elements needed in the wideband array. Specifically, to achieve a -30 dB dynamic range from the system, minimum 31 elements are needed along one-dimension of the 2-D array. Specifications of 2-D array configuration require further detailed investigation.

4.5.1.4 Detection and Recognition

Data acquisition time of the imaging system depends on the chosen transmission scheme of variant UWB technologies. Here we assume a video impulse system with 2 m detection range and 10,000 elements within a planar 2-D array. For the frequency band from 15 – 35 GHz, a pulse of approximately 100 ps duration may be used, which requires a sampling step of 10 ps for accurate measurement. This gives 1,330 samples for each time window. Assuming a 2 m unambiguous range, data acquisition time of a single channel for a stroboscopic receiver will be 18 μs. For the complete array, scanning through all transmit/receive channels would require approximately 0.18 second. With dedicated processing schemes, the system would be just enough to image fast moving objects in real-time.

Until now the detection and recognition of concealed weapons is commonly done by manual screening procedures which are not giving satisfactory results. This is due to the inclusion of human factors in the decision making process that causes rather high false alarm rate. The goal of research is to achieve automatic detection and recognition of concealed weapons. An illustration of a processing scheme for automatic concealed weapon detection after imaging is shown in Figure 28.

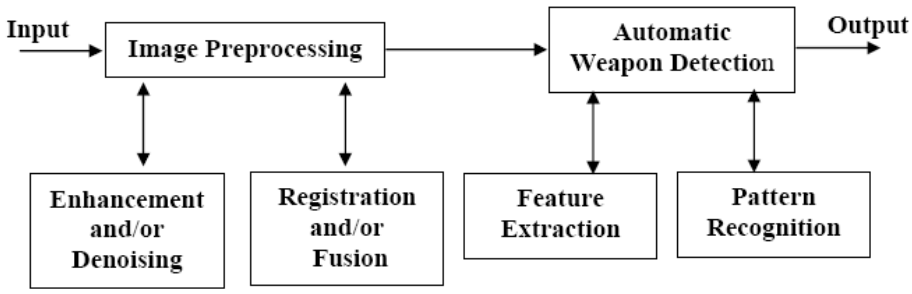

Figure 28 – Image processing scheme for concealed weapon detection

The input can be images from multiple distributed sensors systems of the same target. Variant filters can be applied on the image in order to reduce image noise and enhance hidden features. Registration and Fusion are further performed to align images from different sensors so that they can be merged or treated together. After image pre-processing, detection is done by first extract the feature from the image and compare it with a database of patterns. If the feature of an object within an image matches with a pattern in the library, detection is raised and sent to the security personal. In the case of the presence of multiple objects, an automatic segmentation algorithm has to be used to separate them so that the objects can be classified individually. Although detection and recognition of hidden weapons is possible in principle, the variant type, orientation, distance, and surroundings of weapons post difficulties to achieve a complete automated detection.

4.5.1.5 Current State-of-the-art

In the past, many approaches for concealed weapon detection have been attempted, including metal detector, EM resonance, millimeter wave, and Terahertz systems. Among these options, both millimeter wave and THz systems exhibit imaging capability allowing precise position and identification of a potential threat.

There are two types of millimeter wave (MMW) based screening systems: passive and active. Passive sensor in the millimeter wave regime is fundamentally based on measurement of power received from the scene using radiometer. Passive sensors have the advantage of producing image without emitting any EM radiation. Example images of passive mm-wave system are illustrated in Figure 29. As we can see, the performance can be dramatically different when performed in variant environment.

Figure 29 – Passive mm-wave image taken (left) indoor, and (right) outdoor

In contrast, active millimeter wave sensors illustrate the environment with electromagnetic waves using single or distributed transmitters. Because the transmitted signals have known properties, such system is capable to extract weak target responses from competing sources of noise. Existing active mm-wave sensor already widely deployed at the airports is the ProVision body scanning checkpoint system shown in Figure 30. The exact microwave spectrum applied has not been revealed to the public. The device is claimed to be able to provide quasi-3D images by scanning around the body. This kind of data acquisition approach in certain extent reduces the speed of passenger flow.

Figure 30 – ProVision Body Scanning Checkpoint Security System from L-3 Communications Security and Detection Systems, Inc. (left), and an example of generated 2-D image (right)

The THz imaging technique is based on the use of the THz spectrum to detect concealed explosives, chemical/biological agents, and metal objects using their characteristic reflectivity in the frequency range. A THz reflection image of a person would show the outline of clothing and the reflection of objects beneath, such as concealed weapons. The skin of body would appear dark in the image, thus preventing concerns of violating personal privacy. An example of a passive THz image is illustrated in Figure 31.

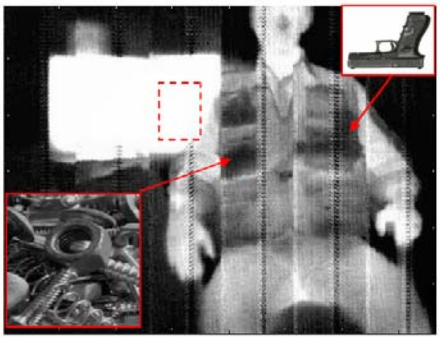

Figure 31 – A passive 1.5 THz image of a test scene where hidden weapons on human body are identified

4.5.2 W band detection sub-system requirements

Measurement setup of the millimetre wave imaging concept. As indicated in the previous items, an accurate imaging of single passengers requires a regular (even a predictable movement) of the persons. Furthermore, they should be forced to enter the imaging area separately to avoid shadowing effects and unscanned body areas. It should be discussed how this could be achieved with a minimal influence of the passenger flow. The imaging sensor will operate at frequencies about 94 GHz, corresponding to a wavelength of about 1 mm. The signal processing is carried out by using the SAR (synthetic aperture radar) principle which presumes knowledge of the radar sensor position and the target (passenger) position with an accuracy corresponding to the wave length. This implies that during the measurement the person should stand still or should conduct a regular movement (like on an escalator or a moving walkway). Otherwise, the radar image gets smeared or completely unfeasible for threat detection.

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One requirement of the ATOM system is a high reliability of the subsystems. The imaging system should be able to detect and classify different dangerous items on the whole body of the passenger. Therefore, for a 360 degree scan, a circular movement of the antenna system is foreseen, as depicted in Figure 32. It shows a person standing on a platform located at the airport ground level. For sake of simplicity, just one radar module is shown which circles the person in less than 2 seconds and records the data. An important criterion of the imaging subsystem is the detection rate of suspicious items. In such a measurement setup where the person is screened under a flat incident angle, most of the transmitted power is reflected away from the transducer. That is why the innovative concept which will be realised in ATOM foresees distributed receivers in order to “look” the dangerous item from different aspect angles. The exact setup of the multistatic concept can be interferometric or polarimetric which has to be investigated in future research during the technical work package.

To get an idea about the radar images, two example images are shown in Figure 33 generated by a monostatic radar with a linear aperture in front of the person. The bandwidth of the system was about 6 GHz with an output power of 1 mW. Figure 33A shows a person with a concealed gun and in Figure 33B a person wearing an explosive belt with multiple vertical positioned explosive pipes. Because the images show just the scattering spots of the dangerous objects, the radar image has to be fused with an optical image for a better interpretation. A sophisticated, complex and expensive antenna array surrounding the person would be also an alternative (like the ProVision system) but is contradictory to the requirement of not disturbing the passenger flow.

Further important criterions of each ATOM subsystem is the *false alarm rate* and the *false acceptance rate*. While the false alarm rate is less critical (a "clean" person is classified as suspicious), the false acceptance rate (dangerous items are not detected) is a hard quality attribute of each security system. These criterions, however, depend on various parameters, especially on the situation the measurement is carried out. For instance, if two persons (one wearing a suspicious object) are walking close to each other such that the suspicious object is completely or partly shadowed by the other person, detection or identification might be impossible. That is why the passengers should be forced to pass separately the security scanning area, e. g. by a tight corridor, for getting ideal "line-of-sight" conditions.

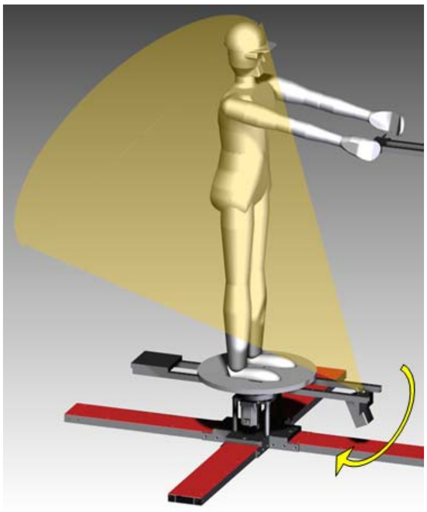


Figure 32 – preliminary setup for screening persons by a rotating radar

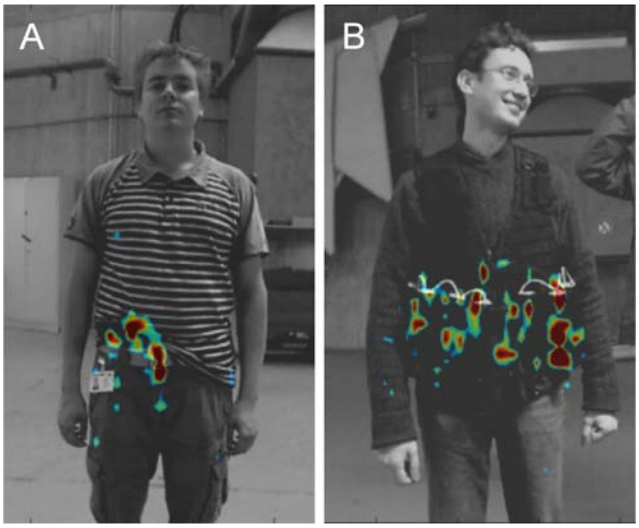


Figure 33 – Image of persons wearing a gun (A) and an explosive belt (B). The radar was moved linearly above the person

Despite that the system does not exist and has still to be built up, the following numbers are given below which mean to be more an estimation for the foreseen imaging subsystem:

Resolution:	5-6 GHz bandwidth yielding a resolution of approximately 3 cm.
Detection:	false alarm rate: 25%
	false acceptance rate: 10%

In order to improve these values, the passenger might be forced to pass more than one imaging subsystem, i.e. three or more concatenated subsystems in a corridor (see Figure 34). During this process, a correct decision whether the person is clean or not can be taken with increasing probability. Moreover, between these systems, tracking modules are mandatory in order to keep the identity of the person. For each generated radar image, it has to be clear which person it comes from. Then, based on these data, the operator is able to decide if the passenger has to undergo a regular inspection or not.

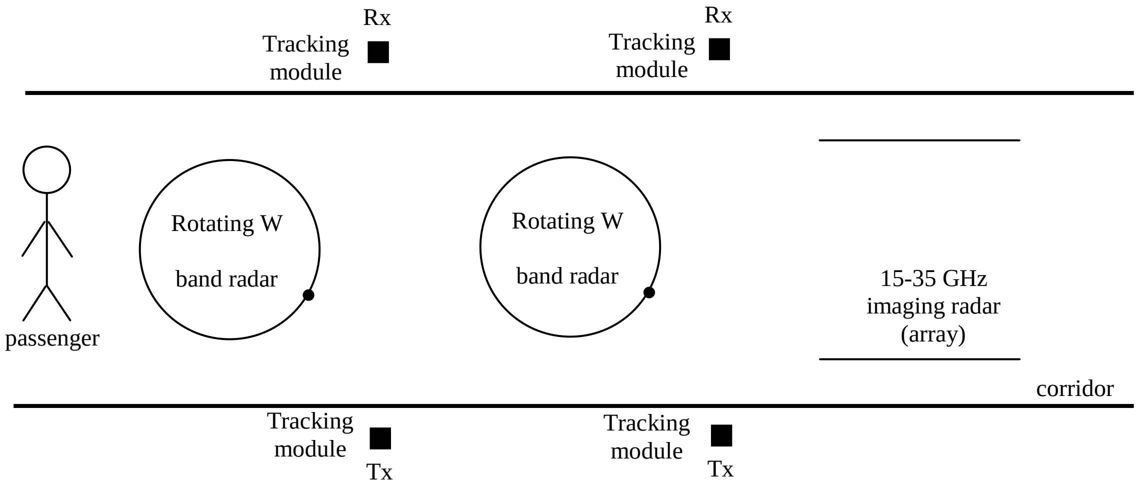


Figure 34 – Sensor fusion of multiple imaging subsystems to determine successively the risk level of a person

4.5.3 Passive tracking radar sub-system requirements

4.5.3.1 Introduction

The purpose is to develop a new passive radar sensor concept for the indoor public airport area surveillance. Aiming at the detection and localization of designated human beings, potentially dangerous or ill-intentioned, the PBR should be based on the best available electromagnetic source of opportunity. Specifically, Local Area Wireless transmissions (e.g., WiFi systems) are however complex and if such a signal is to be used as the basis for passive radar then it is necessary to carry out a detailed analysis in order to assess its feasibility for radar purposes. Moreover, being the performance of the conceived system strongly affected by the particular properties of the transmitted waveform, this will be carefully analyzed and characterized in the first stage of our work in terms of achievable resolution and side-lobe level. The aim of this analysis is to understand the practical feasibility of an indoor PBR and to identify its main limitations. Proper processing strategies will be then developed to counteract these limitations, based on the digital nature of the considered transmissions which allow a partial control of their characteristics affecting the performance of the resulting passive radar.

4.5.3.2 Proposed system

The work aims at the development of a new passive radar sensor concept for indoor surveillance based on available electromagnetic sources of opportunity. Aiming at the detection and localization of designated human beings within a local area, proper signals are considered which can offer reliable detection performance, accurate localization capability and wide availability. For these purposes, one potential illuminator of opportunity which is rapidly growing in coverage is that related to wireless networks. These transmissions sources could thus act as an ideal illuminator of opportunity for short range detection and surveillance using the principles of passive bistatic radar (PBR). Development of a surveillance capability from such a ubiquitous and accessible source will have major implications for improving internal and external security of all types of buildings and in the identification and tracking of goods and people. This type of passive sensing could be used in public areas such as airport terminals. This technique removes the requirements for co-operative targets as used in other wireless or Radio Frequency Identification (RFID) based detection systems and is not subject to the blind spots and potentially intrusive equipment necessary for video surveillance. Moreover, based on the PBR principle, it yields additional advantages such as low cost, small size, covert operation, reduced vulnerability to deliberate e.m. interferences, no additional demand on spectrum resources (which are being progressively allocated for telecommunication applications rather than radar operation), and low-emission characteristics (well in line with modern green-view of technology).

Wireless transmissions (e.g., WiFi) are however complex and if such a signal is to be used as the basis for passive radar then it is necessary to carry out a detailed analysis in order to assess its feasibility for radar purposes. Specifically, the performance of a passive radar based on these kind of transmissions is strongly affected by the particular properties of the transmitted waveform which should be carefully analysed. Moreover, aiming at the monitoring of designated human beings or man-made objects, the required signal processing techniques should be designed to both counteract the disturbance contributions and enhance the detection and localization performance. Finally the feasibility of a multiple sensors network approach should be studied aiming at increasing the system reliability and surveillance performance. Even though there are still many challenges to be solved involving both technology development and processing techniques, PBR is rapidly reaching a point of maturity in long-range surveillance applications. Basically PBR practical feasibility for long range surveillance purposes has been well established, proper signal processing techniques have been designed and different passive radar prototypes/systems have been developed and fielded all over the world. In contrast, to our knowledge, there are not significant contributions available in the open literature addressing the feasibility of WiFi transmissions as waveforms of opportunity for PBR and the exploitation of such systems for local area surveillance applications. Thus, in this work package we aim at spreading the range of applications of PBR with reference to local area monitoring based on Wireless LAN transmissions. It should be noted that the considered innovative application requires a completely new study and a significant effort should be devoted to identify and to solve the peculiar issues of the considered problem.

4.5.3.3 Selection of passive receiver positions and configurations

The performance of the passive radar system is largely dependent on the relative positions of the receivers with respect to the transmitters of opportunity. In details, it is well known that there is no capability to measure range or Doppler frequency along the transmit-receive baseline. Therefore, the receivers must be displaced on the same side of the transmitter with respect to the surveillance area. The example of a typical displacement for a single receiver is reported in Figure 35.

To obtain a higher degree of spatial localization multistatic configurations can be used, whose geometry will be optimised as a part of the WP5. In particular, there are sensor arrangement geometries that must be avoided for the passive radar receiver location with respect to transmitter and surveillance area. Typical case is reported in Figure 36, since in this case the passive radar would have no spatial resolution capability.

Figure 35 – Typical displacement for a single receiver in a Passive Radar System

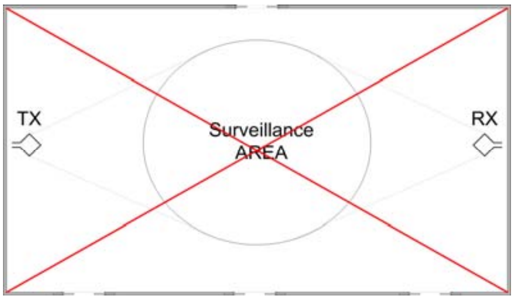


Figure 36 – Example of configuration that must be avoided in a Passive Radar System

In contrast, there are many good solutions for the passive configuration. Among the typical configurations, we consider the case of two or three receivers with a single transmitter of opportunity in Figure 37, that are disposed on the same side of the surveillance area, and the case of two transmitters of opportunity with a single receiver in Figure 38.

In these cases a spatial resolution between 10 and 15 meters is reasonably obtainable by the system. The accuracy in the spatial localisation largely depends on the antenna beam and power settings ,for istance of the WiFi routers, but close enough to the routers it might be even an order of magnitude better than spatial resolution.

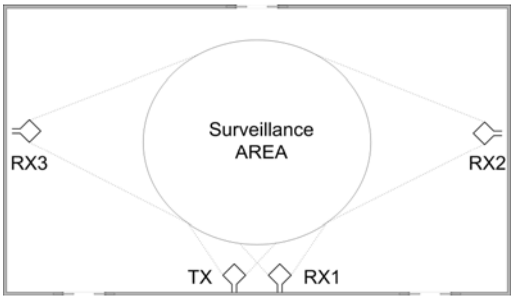


Figure 37 – Typical displacement for a network of receivers in a Passive Radar System

Figure 38– Example of configuration for a Passive Radar System which exploits two transmitters of opportunity

4.5.3.4 Passive tracking sensors:

Number of sensors and observation space of each sensor. The overlap of the observation space of the sensors characterises to what degree the task consists in a task of fusing multiple sensors, or a problem of concatenating sensor information (both in central/decentred sensor fusion). It also characterises the dimensionality of the problem (differences in magnitude below ten and above 100 are not only a numerical problem).

***Connectivity of the observation space*.** Tracking requires continuity of the observed process. In an airport within large entrance halls a continuous observation of individual targets may not be possible. Characterisation of observation spaces where continuous observation is possible is necessary (corridors, stairs). An open question is how then the information between different observation spaces can be fused.

Accuracy and resolution of each sensor. The resolution of the sensor determines to what extent targets can be associated to tracks and how long individual tracks can be kept. The accuracy of the sensor determines (among others) the size of the expected target region. If these quantities are not sufficient, small tracking of a possible dangerous target will not be possible, i.e. association of a dangerous and a normal track will not be possible after a crossing of both tracks. Additional remarks:

- Insufficient resolution cannot be overcome by multiple sensors if all these have the same insufficient resolution.
- Accuracy and resolution must also be related to the available update rate and the number of sensors.

Existence of dynamic target models. A dynamic model is the basis of prediction and tracking algorithms. For vehicles, in particular aircraft, these models are very accurate. For pedestrians a dynamic model is difficult. An appropriate model may exist in corridors and doors, where the dynamic model is then also an indicator of a normal behaviour. However, in a waiting lounge people may perform a random walk, something which is unpredictable. This leads to unobservable spaces (in a tracking sense). The question is if additional sensors are available in these region (optical/ TV image flow analysis) and how these might be exploited.

4.5.3.5 Passive Tracking System

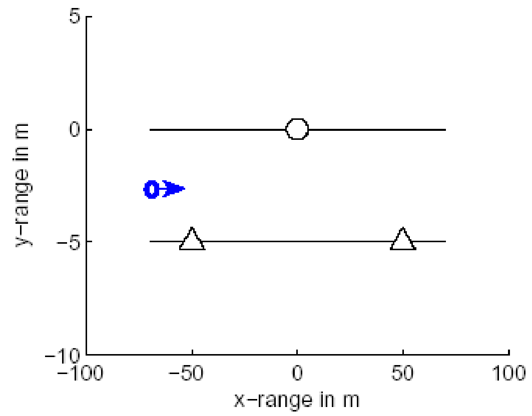
4.5.3.5.1 Introduction

For a definition of the ATOM sensor systems bounds on the performance of the included subsystems will be necessary. For this purpose we have evaluated for the passive tracking part calculated Cramér-Rao bounds (CRB) for different amounts of sensor errors for very simple standard scenarios. This can help to substantiate our requirements on the sensor. Of course, the CRB gives only a rough estimate. Techniques to improve these values can be a point of further discussions.

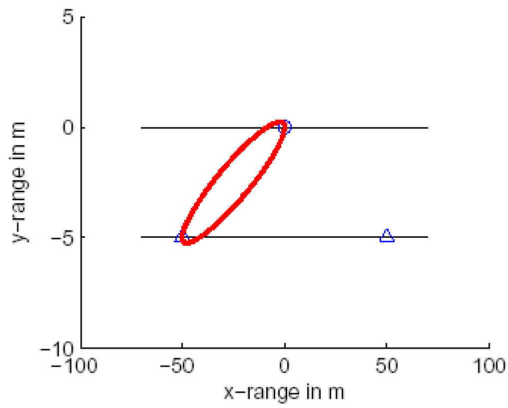
In sections below we have studied the CRB for the position estimate in Cartesian coordinates based on a single measurement of the selected sensors. In section 4.5.3.5.4 we present preliminary tracking results.

4.5.3.5.2 Selected Tracking Scenario

We consider a worst-case scenario with two different sources and one single passive receiver. The sources and receivers are installed at the walls of a corridor of 5m width. The scenario is depicted in Figure 39(a). This is the worst case for a passive radar sensor and in this case the tracking system is in charge of providing the localization requirement. While this configuration will be not the best selection for the system, it allows us to show how powerful an appropriate tracking system can be in increasing the system performance.



(a) ATOM tracking scenario: target (blue circle) moves across the corridor



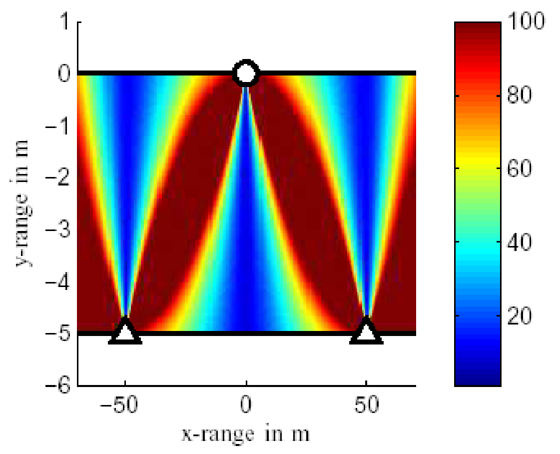
(b) ATOM tracking scenario: ellipse demonstrates the bistatic range measurement of a target at (−40m,−3m)

Figure 39 – Tracking scenario: Corridor with two sources (triangles) and a single passive receiver (circle); target moving across the corridor is shown by blue circle.

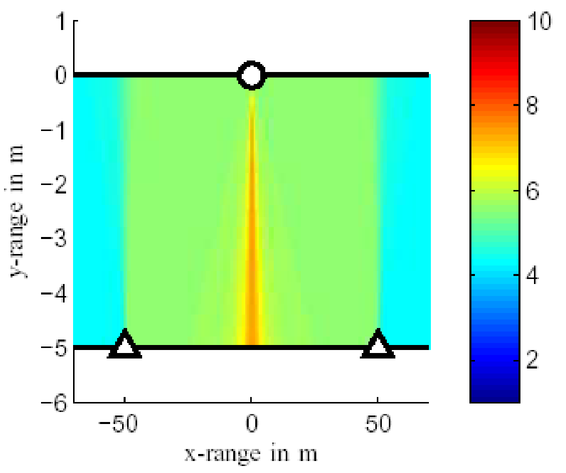
4.5.3.5.3 Analysis of Estimation accuracy performance

We assume that the receiver is capable to receive target echos from both transmitters. This will result in two bistatic range measurements. For a grid of possible target positions we calculate the Cramer Rao Bound (CRB) of the position estimate as a measure of the best case estimation performance. We have plotted the overall standard deviation (std) given by the CRB ($\sqrt{\sigma_x^2 + \sigma_y^2}$). The std of the bistatic range is set σ_r= 10m. Results are shown in Figure 40(a). First, we note regions of poor estimation performance around the Tx/Rx baseline. On the Tx/Rx baselines the received Doppler shift is zero, which is equivalent to the range-rate. Since the derivative of our measurements with respect to the estimated parameter is zero, the CRB is infinitely large, or in other words, such measurement gives no information in the Fisher sense. Secondly, if the target is in line with both illuminators but not on the segment between the two illuminators two independent measurements cannot be provided. Then the derivatives become collinear and the Fisher matrix is not invertible.

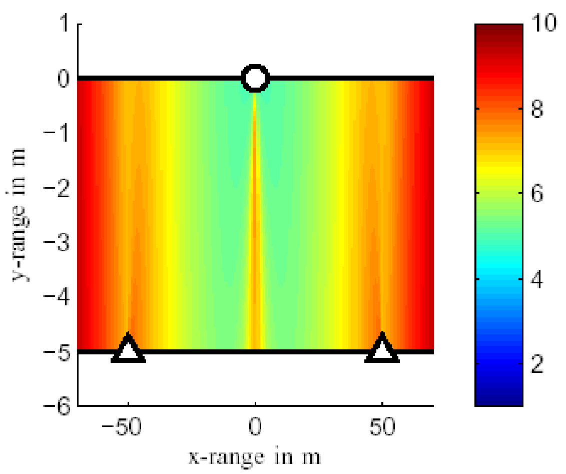
Considering the depicted scenario the achieved performance is inadequate for target tracking, especially in the regions near to the Tx and Rx positions. Figure 40(b) shows the same results but with a-priori information about the corridor included (corridor width=5m). We achieve best estimation performance far from the sensors (but this coincides with the regions, where the receiver is not likely to detect our target due to the limited coverage), but also close to the baseline region we obtain errors below 10m. Figure 40(c,d) shows the case of additional azimuth measurements with std σ_φ=10° (c) and σ_φ = 5° (c). Here the corridor information is not considered. We note that the additional azimuth measurement results in improved estimation performance in the vicinity of the receiver.



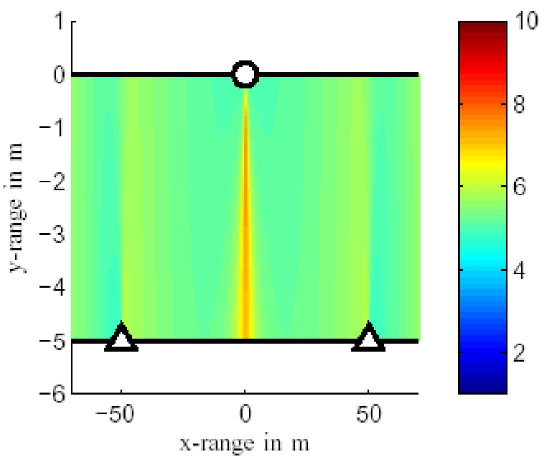
(a) CRB: bistatic range measurements of two Tx/Rx pairs



(b) CRB: bistatic range measurements of two Tx/Rx pairs; corridor information included



(c) CRB: bistatic range measurements of two Tx/Rx pairs; azimuthmeasurement included (σ_φ=10°)

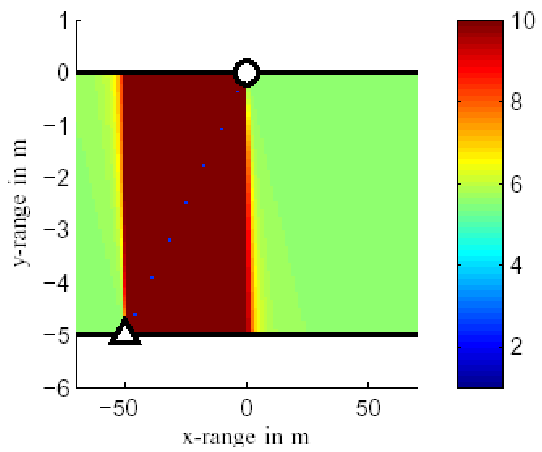


(d) CRB: bistatic range measurements of two Tx/Rx pairs; azimuth measurement included (σ_φ=5°)

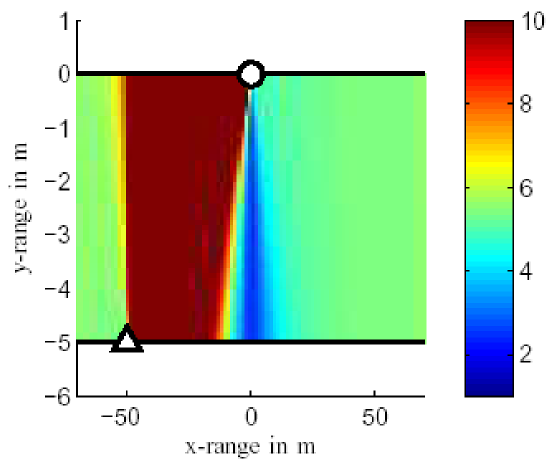
Figure 40 – CRB of position estimate (two Tx/Rx pairs). Note the different scalings of the colorbar in (a) and (b,c,d).

In reality target detection by both two Tx/Rx pairs is not always guaranteed. Therefore we show in Figure 41 the case of a single source (at (−50m,−5m)). In Figure 41(a) we consider bistatic range measurement together with corridor information, in Figure 41(b) we consider additionally an azimuth measurement with std σ_φ = 5°. Again the bistatic range gives only poor information about the target position in the region between Tx and Rx. The improved performance in Figure

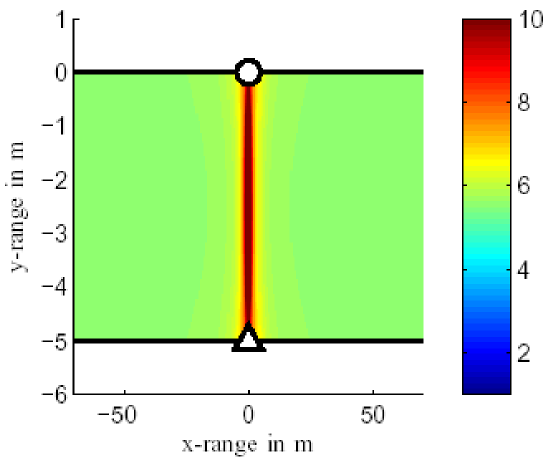
39 can be explained by the optimum alignment of the Tx and Rx position. The poor performance indicated in Figure 39(b) is explained as follows: The bistatic measurement of a target at (−40m,−3m) is illustrated by an ellipse. The projection of the error ellipses on the x- and y-axes then gives a localization error of about 50m, which is the distance between source and receiver.



(a) CRB: bistatic range measurements of one Tx/Rx pair: corridor information included



(b) CRB: bistatic range measurements of one Tx/Rx pair: corridor information and azimuth measurement (σ_φ = 5°) included



(c) CRB: bistatic range measurements of one Tx/Rx pair: corridor information included

Figure 41 – CRB of position estimate (one Tx/Rx pair)

To improve the localization performance we propose to place transmitter and receiver at close distance, c.f. Figure 41(c). For multiple transmitters this placement has to be optimized.

4.5.3.5.4 Tracking performance for depicted scenario

Next we consider a target tracking scenario. We assume two targets (target 1 and target 2) starting at −60m and −30m, see Figure 42(a). Target 1 is moving with 1.5m/s in x-direction, target 2 has a lower velocity at 0.5m/s in x-direction. The targets are walking along the corridor for 100 seconds; bistatic range measurements (σ_r = 10m) are generated every second.

We analyze three different scenarios:

- scenario A: Only consider measurements of target 1: Probability of detection is set to P_D = 1 for both Tx/Rx pairs and no false alarms are generated.
- scenario B: Only consider measurements of target 1: Probability of detection is set to P_D = 0.6 for both Tx/Rx pairs and one false alarm per time scan and for each source and receiver pair is generated uniformly in bistatic range(in the interval [0km,100km] corresponding to a probability of false alarm P_{FA}=0.01).
- scenario C: As scenario B (P_D = 0.6 and P_{FA} = 0.01), but measurements of target 2 are available additionally. Two different targets of the same Tx/Rx pair are assumed to be unresolved if the distance in bistatic range is below 10m. The corresponding scans, when the targets are unresolved each of the two Tx/Rx pairs are depicted in Figure 42(b).

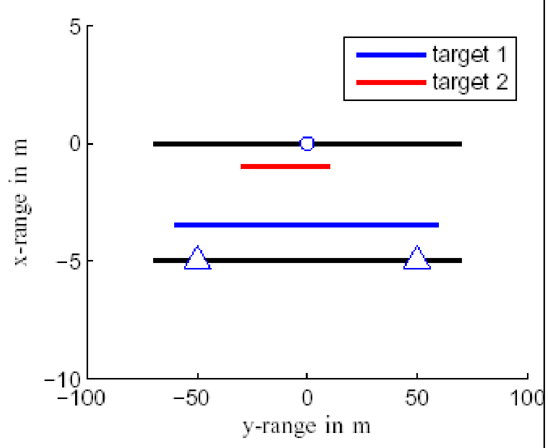
We simulated the three scenarios by 10^3 Monte Carlo Runs. Each track is initiated with a std of 10m in x and y range each.

	target 1	target 2	P_D	P_{FA}
scenario A	✓		1	0
scenario B	✓		0.6	0.01
scenario C	✓	✓	0.6	0.01

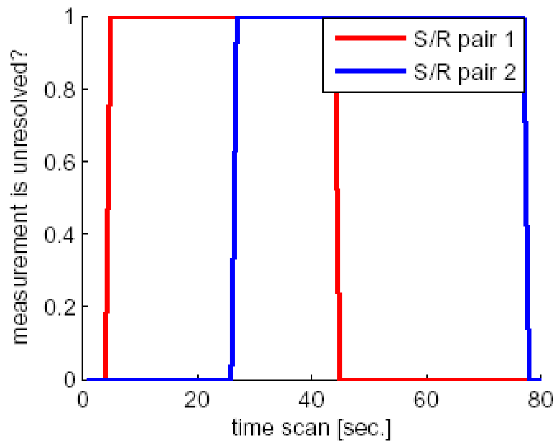
Table 6 – Summary of tracking scenarios

Figure 42(c) shows the tracking results by the root mean squared error of the position (RMSPOS) of target 1. These results include incorporation of a-priori knowledge about the corridor. Scenarios A and B show the improvement due to target tracking, assuming constant target velocity. Scenario B shows how performance is degraded by false alarms and missed detections. Scenario C shows the worst performance arising from the resolution conflict between the two targets. In case of a resolution conflict the centre of gravity of the two targets is tracked.

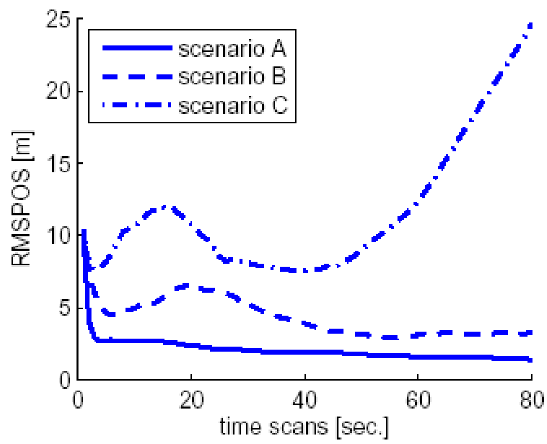
Around time index 38 this centre happens to coincide with the true position and therefore RMSPOS shows smaller values. The large errors at the end of the track show that the tracker is not always able to keep the identity of tracks. More studies of the tracking case are needed.



(a) tracking scenario: two targets, two sources (triangles) and one receiver (circle)



(b) Unresolved measurements for Tx/Rx pair 1 and 2 respectively



(c) preliminary tracking results

Figure 42 – Sequential target tracking

4.5.3.5.5 Conclusion

- Bistatic range measurements alone delivers insufficient target estimation accuracy
- Estimation accuracy can be improved by additional a-priori information like a corridor of given width or and additional azimuth measurements. In the scenario considered here we achieved localisation accuracy of about 6m
- Localisation can further improved by target tracking provided that an adequate movement model for the target is available
- Suitable receiver placement is crucial for passive target localization In the course of the ATOM project analyzing resolution conflicts between different peoples will be a challenge.

Important questions:

- Is it possible to separately track different persons walking at close distance?
- Is it possible to retain identity of tracks after a crossing of person’s paths?

4.5.4 Active tracking radar sub-system requirements

4.5.4.1 Introduction

The purpose is the development of an active distributed RF sensor concept, able to track designated people. Active RF sensors are robust against smoke or dust and are able to provide a robust picture even during calamities.

The system will consist of several active radar nodes to increase the accuracy and performance of the system. The required processing techniques, including advanced tracking algorithms, will be designed and simulated in a realistic environment to support the performance analysis and provide a simulation demonstration.

Designation of suspect persons will be performed after identification of dangerous goods by either K-band radar (WP6, TU Delft) and/or; W-band radar (WP3, FGAN).

The active RF sensor system will consist of several active radar nodes. Several configurations will be examined with nodes measuring range and/or Doppler velocity. Because of the active nature of the sensors, main challenges of the concept are:

- robustness against interference; and may not interfere with other equipment.
- Allowed e.m. field strength is limited by health regulations. Radar approaches in other public spaces (e.g. automotive radar sensors, door openers, velocity measuring radar) will be studied on their approach for this topic.

The other main challenges is how to fuse the data from the different nodes and how to track the designated persons in a crowded environment. After functional specification of the distributed RF system, a simulator will be developed and simulations performed.

Finally a laboratory demonstration will be given of the system.

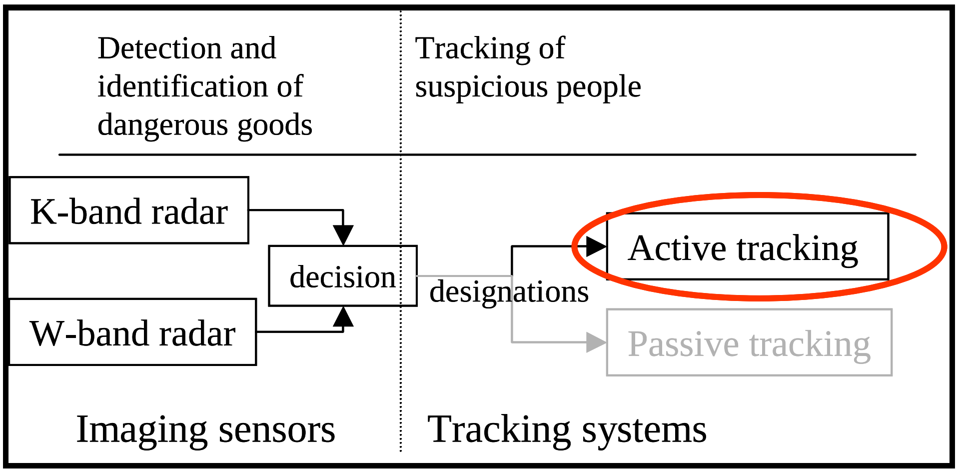


Figure 43 – Overview of the different functional roles of the ATOM system. Highlighted in red the TNL contribution

4.5.4.2 Capabilities

A schematic overview of the system is given in Figure 44. This is only meant as example, as several trade-offs about the location of functionality still has to be made (e.g. local or central detection and tracking).

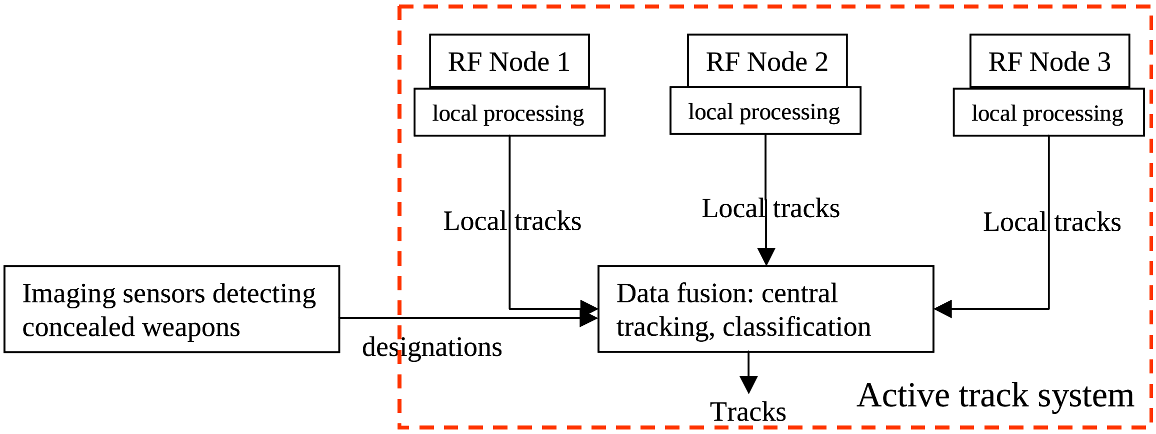


Figure 44 – Schematic overview active tracking system

Detection and tracking: the system must be able to detect and track designated (suspicious) persons and the detect and track unsuspicious persons, in order not to confuse suspicious and unsuspicious persons in a more complex scene. The following subcapabilities are required:

- High resolution; preferably in range, Doppler and azimuth. Different combinations (Doppler-only, range-Doppler etc) will be examined.
- Sensitivity: the system must be sensitive, but must not be overloaded by the activity within the surveillance area or its background.

Data fusion: algorithms must be developed to fuse the data from the different nodes.

Classification: persons must be classified from other moving objects and from the background. The most distinguishing features will be examined and chosen to build a reliable classifier.

Environmental aspects: in public space, many environmental aspects must be taken into account, of which the following are the most relevant:

- Interference: low power concept; frequency/time sharing concept
- Health regulations: low power concept
- Visibility equipment: a low profile exterior is preferred in public space. This dictates preferably small nodes (max. order of few decimetres)

Infrastructure: this includes the possible placement of the nodes, the communication between the nodes and between the end user and the power supply.

4.5.5 Data fusion and management sub-system requirements

4.5.5.1 Introduction

In the last years more types of sensors have become available and the problem of data fusion becomes more relevant. The need to fuse the data coming from different sources can be an advantage to extract more useful information than a single type of sensor. In fact Multi-sensor data fusion seeks to combine information from multiple sensors and sources to achieve inferences that are not feasible from a single sensor or source. The fusion of information from sensors with different physical characteristics enhances the understanding of our surroundings and provides the basis for planning, decision-making, and control of autonomous and intelligent machines. Multi-sensor data fusion is a process of combining images, obtained by sensors of different wavelengths to form a composite image. The composite image is formed to improve image content and to make it easier for the user to detect, recognize, and identify targets and increase situational awareness. In the ATOM project the management of the different sub-systems and the sharing of data from the different devices represent one of the added values of the project. The data from the different sensors will convey in a unique data management block that will provide an opportune data fusion, taking into account:

- Outputs from the ATOM sensors;
- dislocation (or placement or deployment) of the sensors in the airport area;
- accuracies of the different sensors;
- data rate and data refresh of the different sensors.

The output of the data management block will be an innovative data that will include all the available information on dangerous or potential dangerous tools and/or material, their positions, the alert level (taking into account the proximity of the dangerous tools to sensible areas).

While the concept of data fusion is not new, the emergence of new sensors, advanced processing techniques, and improved processing hardware makes the fusion of data increasingly viable.

Applications for multisensor data fusion are widespread. Military applications include: automated target recognition (e.g., for smart weapons), guidance for autonomous vehicles, remote sensing battlefield surveillance, and automated threat recognition systems, such as Identification-Friend-Foe-Neutral (IFFN) systems. Nonmilitary applications include monitoring of manufacturing processes, condition-based maintenance of complex machinery, robotics, air traffic control, homeland security and medical applications. Historically, data fusion methods were developed primarily for military applications. However, in recent years, these methods have been applied to civilian applications and there has been bidirectional technology transfer. They have been widely used in many fields of remote sensing, such as object identification, classification, and change detection.

4.5.5.2 Characteristics

The fusion of different types of sensors can provide several possible advantages respect to a single sensor.

First, if several identical sensors are used (e.g., several identical radars used to track a moving object), then an improved estimate of the target position and velocity will result if the observations are combined. A statistical advantage is gained by adding the N independent observations, ie., the estimate of the target location or velocity is improved by a factor proportional to ($N^{1/2}$), assuming the data are combined in an optimal way. This same result could also be obtained by combining N observations from an individual sensor.

A second advantage may be obtained from multiple sensors by using their relative placement or motion to improve the observation process. For example, two sensors which measure angular directions to an object, can be coordinated to determine the position of an object by triangulation. This technique is used in surveying and for commercial navigation. Similarly, the use of two sensors, one moving in a known way with respect to another, can be used to instantaneously measure an object’s position and velocity with respect to the observing sensors.

A third advantage obtained by the use of multiple sensors is improved observability. By broadening the baseline of physical observables, significant improvements can often be achieved. In Figure 45 a simple example is provided of a moving object, such as an aircraft, observed by both a pulse radar and an infrared imaging sensor. The radar provides the ability to accurately determine the aircraft’s range, but has a limited ability to determine the angular direction of the aircraft. By contrast, the infrared imaging sensor can accurately determine the aircraft’s angular direction, but is unable to measure range. If these two observations are correctly associated (as shown in Figure 45), then the combination of the two sensors provides an improved determination of location than could be obtained by either of the two independent sensors. This results in a reduced error region as shown in the fused or combined location estimate. A similar effect may be obtained in determining the identity of an object based on observations of an object's attributes.

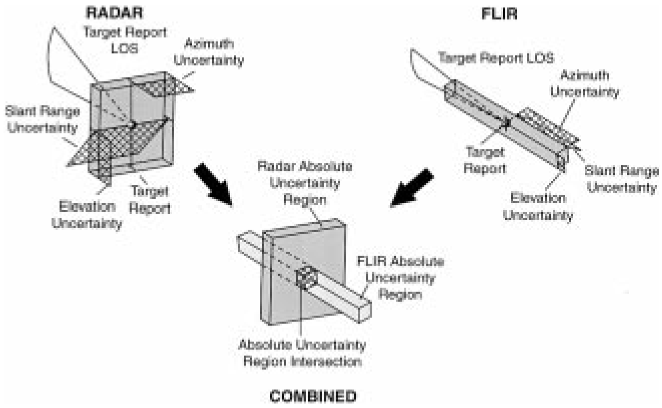


Figure 45 – Advantage of sensor data fusion

In the following some advantages about multisensor data fusion are listed:

- Increased confidence: more than one sensor can confirm the same target
- Reduced ambiguity: joint information from multiple sensors reduces the set of hypotheses about the target
- Improved detection: integration of multiple measurements of the same target improves signal-to-noise ratio, which increases the assurance of detection
- Increased robustness: one sensor can contribute information where others are unavailable, inoperative, or ineffective
- Enhanced spatial and temporal coverage: one sensor can work when or where another sensor cannot
- Decreased costs: a suite of "average" sensors can achieve the same level of performance as a single, highly-reliable sensor and at a significantly lower cost.

On the other hand some issues remain open:

- Nature of sensors: different type of sensors produce a different output and greater difficulty in data fusion (Figure 46).
- Location: sensors (even of the same type) observe the same scene from different point of view and in different times (Figure 47).
- Computational ability of the different type of sensors
- Communication structure
- If fusion algorithms generate a fused image from a set of pixels in the various sources, they are very sensitive to registration accuracy, so that co-registration of input images at sub-pixel level is required;

Within this context emerges the multisensor detection problem: given a number of sensors although of different kinds, all the single outputs enter in a data fusion center which takes a decision according to a fixed rule.

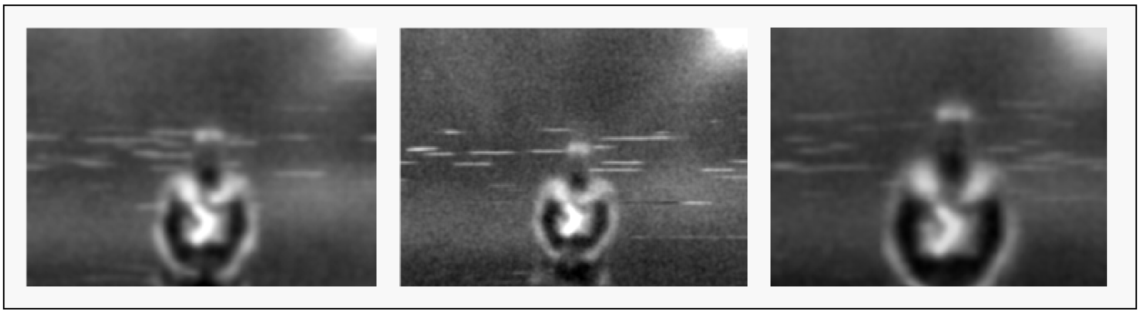


Figure 46 – Images taken at the same time, but from different type of sensors

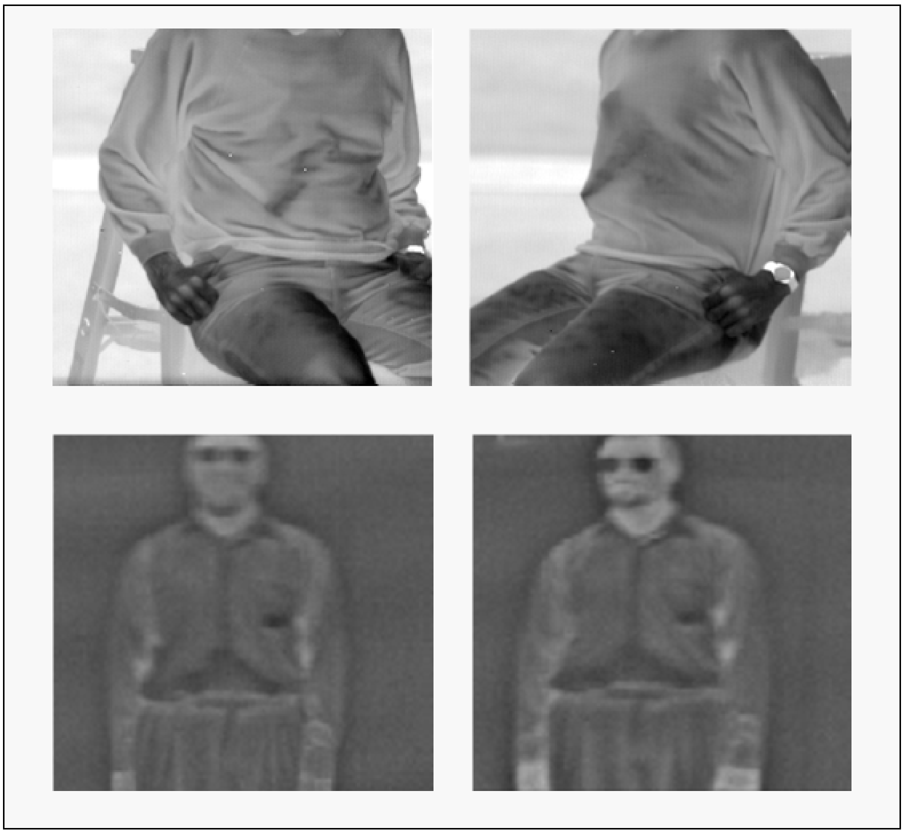


Figure 47 – Images taken from the same sensor but different viewpoints

4.5.5.3 Multisensor detection problem

The signal detection problem is based on two hypothesis testing: determination of the presence or absence of a target. These two hypotheses are generally called $H_1$and H_0. In the case of only a single sensor, the Figure 48 explains the detection process.

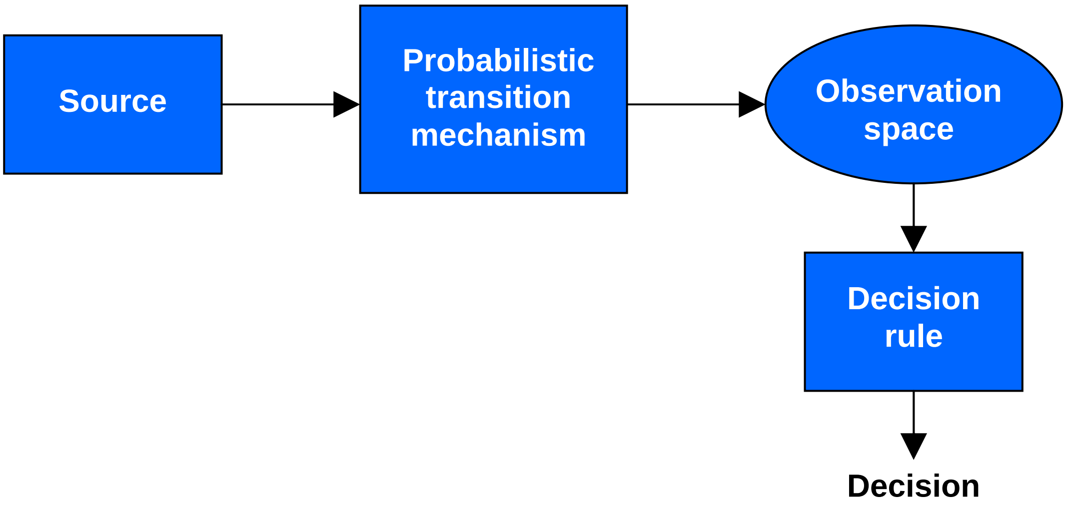


Figure 48 – Components of a hypothesis testing problem

Figure 49 shows the scenario in case of multiple sensors observing the same phenomenon.

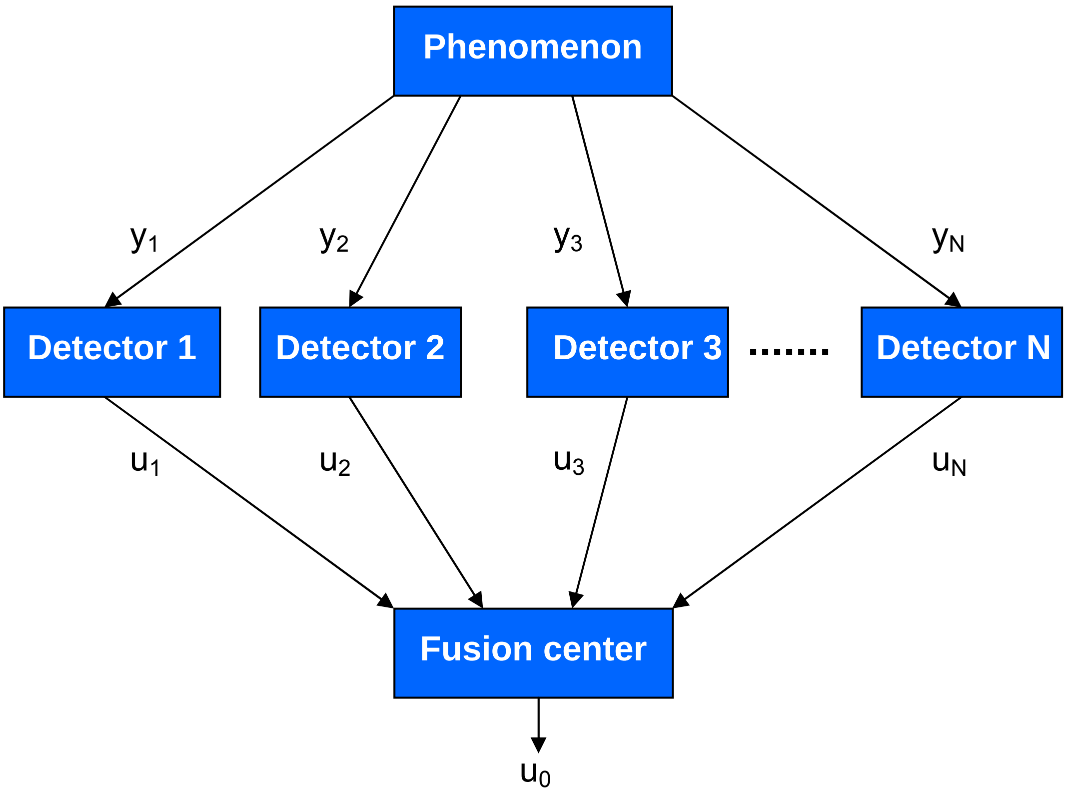


Figure 49 – Parallel fusion network

After observing the scene, the sensors collect their observation called $y_1,\ldots y_N$. Each sensor produce a local decision called $u_1\ldots u_N$. A single decision can be H_0 or H_1. The set of multiple decisions enters in the fusion center (Figure 50).

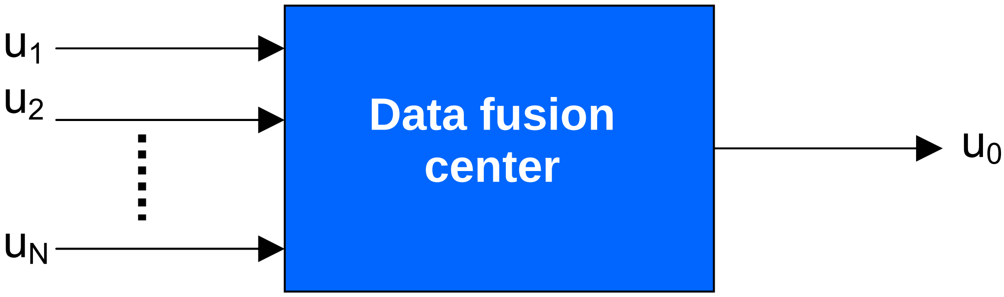


Figure 50 – Data fusion center

If we consider the detector *i* (*i=1,…,N*), the input of the fusion center will be 0 if the detector *i* decides H_0 while it will be 1 if the detector *i* decides H_1. The fusion rule is a logical function with *N* binary inputs and one binary output. After analysing all the input, the fusion center decides the output u_0, that will be 0 if it decides H_0 while it will be 1 if it decides H_1. The number of the fusion rule is 2^{2N}. The Table 7 is an example of possible fusion rules for two binary decision.

Input		Output u_0															
u_0	u_1	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}
0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
1	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Table 7 – Possible decision rule for two binary decision

4.5.5.4 Concept of image fusion

4.5.5.4.1 Categorization of the algorithms

As we said in the previous paragraphs, data fusion is a process dealing with data and information from multiple sources to achieve refined/improved information for decision making. Image fusion is performed at four different processing levels according to the stage at which the fusion takes place (Figure 51):

1) Signal level fusion:

   In signal-based fusion, signals from different sensors are combined to create a new signal with a better signal-to noise ratio than the original signals

2) Pixel level fusion:

   Pixel-based fusion is performed on a pixel-by-pixel basis. It generates a fused image in which information associated with each pixel is determined from a set of pixels in source images to improve the performance of image processing tasks such as segmentation

3) Feature level fusion:

Feature-based fusion at feature level requires an extraction of objects recognized in the various data sources. It requires the extraction of salient features which are depending on their environment such as pixel intensities, edges or textures. These similar features from input images are fused

4) Decision-level fusion:

It consists of merging information at a higher level of abstraction, combines the results from multiple algorithms to yield a final fused decision. Input images are processed individually for information extraction. The obtained information is then combined applying decision rules to reinforce common interpretation.

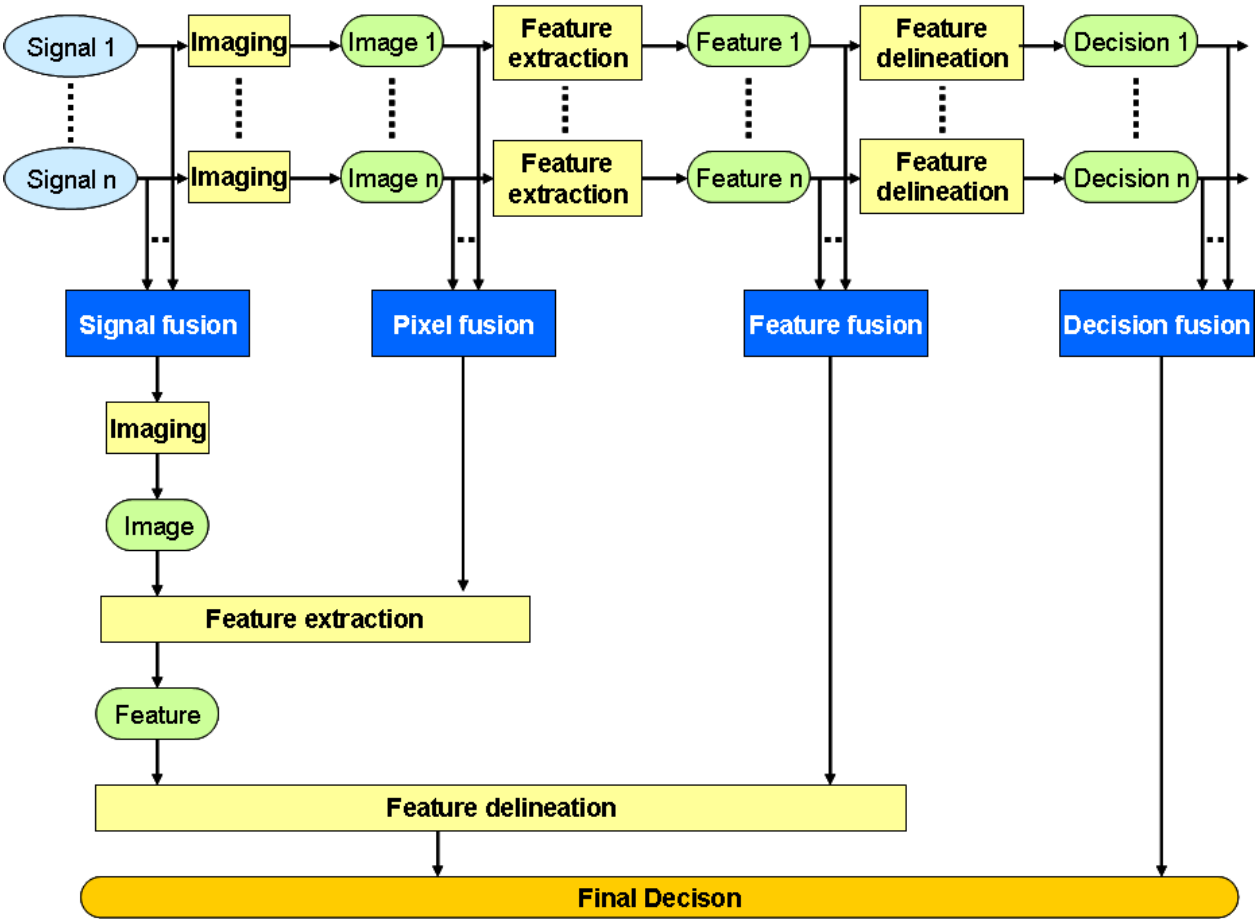


Figure 51 – Processing levels of image fusion

Preliminary information	Signal level	Pixel level	Feature level	Detection level
Bandwidth	possibly very large	large	medium	very small
Information loss	No loss	low	some	possibly significant
Performance loss	No loss	low	some	possibly significant
Operational complexity	high	High/medium	medium	low

Table 8 – Features of different level fusion

4.5.5.5 Fusion algorithms

In the literature we can find several types of algorithm for image fusion. The most popular and effective methods include, intensity-hue-saturation (IHS), principal component analysis (PCA), different arithmetic combination (e.g., Brovey transform), multi-resolution analysis-based methods (e.g., pyramid algorithm, wavelet transform), and Artificial Neural Networks (ANNs).

4.5.5.5.1 Standard Fusion algorithms

The PCA transform converts inter-correlated multi-spectral (MS) bands into a new set of uncorrelated components. To do this approach first we must get the principle components of the MS image bands. After that, the first principle component which contains the most information of the image is substituted by the panchromatic image. Finally the inverse PC transform is done to get the new RGB (Red, Green, and Blue) bands of multi-spectral image from the principle components.

The IHS fusion converts a color MS image from the RGB space into the IHS color space. Because the intensity (I) band resembles a panchromatic (PAN) image, it is replaced by a high-resolution PAN image in the fusion. A reverse IHS transform is then performed on the PAN together with the hue (H) and saturation (S) bands, resulting in an IHS fused image.

Different arithmetic combinations have been developed for image fusion. The Brovey transform, is a successful example. The basic procedure of the Brovey transform first multiplies each MS band by the high resolution PAN band, and then divides each product by the sum of the MS bands.

The Standard fusion algorithms mentioned above have been widely used for relatively simple and time efficient fusion schemes. However, three problems must be considered before their application:

1) Standard fusion algorithms generate a fused image from a set of pixels in the various sources. These pixel-level fusion methods are very sensitive to registration accuracy, so that co-registration of input images at sub-pixel level is required;
2) One of the main limitations of HIS and Brovey transform is that the number of input multiple spectral bands should be equal or less than three at a time;
3) Standard image fusion methods are often successful at improving the spatial resolution, however, they tend to distort the original spectral signatures to some extent. More recently new techniques such as the wavelet transform seem to reduce the color distortion problem and to keep the statistical parameters invariable

4.5.5.5.2 Wavelet-based methods

One of the most common fusion method in remote sensing in recent years is wavelet transform fusion. Wavelet transforms provide a framework in which an image is decomposed, with each level corresponding to a coarser resolution band. For example, in the case of fusing a MS image with a high-resolution PAN image with wavelet fusion, the Pan image is first decomposed into a set of low-resolution Pan images with corresponding wavelet coefficients (spatial details) for each level. Individual bands of the MS image then replace the low-resolution Pan at the resolution level of the original MS image. The high resolution spatial detail is injected into each MS band by performing a reverse wavelet transform on each MS band together with the corresponding wavelet coefficients. In the wavelet-based fusion schemes, detail information is extracted from the PAN image using wavelet transforms and injected into the MS image. (Figure 52).

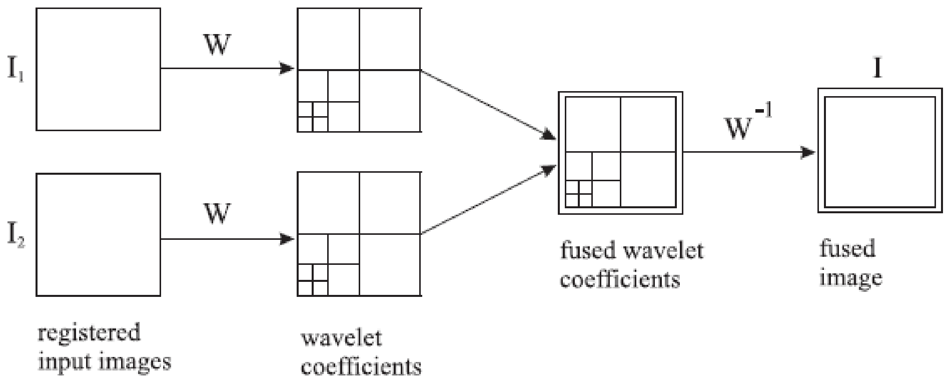


Figure 52 – Fusion of the wavelet transforms of two images

Problems and limitations of wavelet transform method are:

1) Its computational complexity compared to the standard methods;
2) Spectral content of small objects often lost in the fused images;
3) It often requires the user to determine appropriate values for certain parameters (such as thresholds).

The development of more sophisticated wavelet-based fusion algorithm (such as Ridgelet, Curvelet, and Contourlet transformation) could improve the performance results, but these new schemes may cause greater complexity in the computation and setting of parameters

In the next table the most relevant features of the fusion method previously described are listed:

Method	Benefits	disadvantages
Standard fusion algorithms (PCA, IHS, Brovey transform, etc.)	lower complexity and faster processing time	color distortion the number of input multiple spectral bands should be equal or less than three at a time
Wavelet transforms	better in terms of performance	greater complexity in computation and parameters setting

Table 9 – Comparison between different fusion method

4.5.6 ATOM network infrastructure issues

In order to define the network requirements, a priori knowledge of the security system elements is needed which is not known at the moment but will come out as output of previous WPs. Below we provide some info regarding possible technology solutions as well as issues that should be known/considered in order to define the system architecture.

In order to be able to extract/define the architecture and implementation details of the network that will be used for the integration of the sensors of the ATOM system and the distribution of the collected info, we must first determine the technology (protocol) that will be used by the wireless network. Commonly used technologies (for ad-hoc networking) include[3]:

- ZigBee
- IEEE 802.11 (Wi-Fi)
- Ultra WideBand (UWB)

Each one has its one characteristic regarding bandwidth and range which differ significantly, so in order to proceed with the selection it is necessary to know at least the following:

1) The type of sensors that will be used and more specifically:
    - sensor type
    - their available interface for sending data (i.e. will they be equipped with a wireless interface, what ports they have: Ethernet, serial etc)
    - whether or not the sensor nodes are or should be individually addressable
    - whether the sensors need to inter-communicate or just report centrally
    - the number of sensors deployed (at least in term of order of magnitude)
2) The range of communication required (the technologies given above are mostly short range but still vary significantly regarding the distance that they are able to cover
3) Whether the communication needs to be 2-way (i.e. the sensors will also receive any type of data)
4) Requirements related to the level of security that is needed for the exchanged data

At a second level:

5) Some knowledge of the overall physical environment is required.
6) Information regarding the existing airport infrastructure and the possibility of utilizing its resources

A crucial question is whether we really require true ad hoc networking and why?

ZigBee is a true ad hoc wireless technology. There are commercial solutions but it has certain limitations in bandwidth and a drawback is that it uses its own protocol stack (not IP based). It is most suitable for wireless personal area networks (WPANs).

[3] NFC & Bluetooth are set aside since they are of very low range

IEEE 802.11 is of course the most widely used communication technology and probably the one that will ensure easier compatibility with existing infrastructure since it is IP based. As such it arises as the most suitable candidate. However, most wireless LANs today utilize "infrastructure" mode that requires the use of one or more access points. With this configuration, the access point provides an interface to a distribution system (e.g. Ethernet), which enables wireless users to utilize corporate servers and Internet applications. As an optional feature, however, the 802.11 standard specifies "ad hoc" mode, which allows to operate in what the standard refers to as an independent basic service set (IBSS) network configuration. With an IBSS, there are no access points. Devices communicate directly with each other in a peer-to-peer manner.

UWB on the other hand allows great volume of data but it is a rather new technology with few if any reliable commercial solutions.

There is also a possibility of mixed solution where i.e. ZigBee is used for the integration of the sensors of ATOM system and some nodes may act as the cluster masters, providing connectivity to informative network of the airport through a longer range radio interface using a protocol such as IEEE 802.11

4.5.7 Functional requirements

This section shows the data which intend to define the functional requirements of the ATOM sub-systems. In the next table the main characteristics of each sub-system are listed in order to give at least an indication value which is as plausible as possible for each subsystem.

	Detection system		Tracking system	
	15-35 GHz	W band	Active	Passive
Detection Performance (for each object category)				
Probability of Detection	80%	90%	60%	60%
Probability of False Acceptance	20%	10%	10-20%	10-20%
Probability of False Rejection	N/A	25%	N/A	N/A
Data characteristics				
Output data format	MATLAB figure, mat, jpg	MATLAB fig, jpg, avi movie	Tracks	position vector and velocity
Refresh time	Order of seconds	0.5 s	Order of seconds	Order of seconds
Data resolution	10 mm (both azimuth and range)	3mm (azimuth), 4 cm (range)	order of meters	10-16 m
Time				
Acquisition time	10 s	4 s	Order of seconds	Order of seconds
Processing time	20 s	40 s	Order of seconds	Order of seconds

Table 10 – Main characteristics of ATOM sub-system

In the following table are listed the characteristics of the overall ATOM system. Also in this case the number should be considered only indicatives: they are mostly estimated. The reported parameters are extrapolated from the subsystems performance table, taking in account also the system architecture and the added values of the data-fusion component. The achieved performance/quality synthesis table represents the objective to be achieved by a system prototype in a lab. environment.

	ATOM system	
	Detection system	**Tracking system**
Detection Performance		
Probability of Detection	> 90%	> 65%
Probability of False Acceptance	< 10%	< 15%
Probability of False Rejection	25%	N/A
Data characteristics		
Output data format	Image/classification	Track
Refresh time	0.5 s.	Order of seconds
Data resolution	3mm (azimuth), 4 cm (range)	< 5 m.
Time		
Acquisition time	15 s.	< 1 s.
Processing time	40 s.	< 1 s.

Table 11 – Main characteristics of overall ATOM system

4.5.8 Requirements match points

In this paragraph we want to find the most relevant match points between the high level requirements and the other sub-system requirements. For best clarity a list of all sub-system requirements will follow and then a table will be depicted.

4.5.8.1 List of requirements

4.5.8.1.1 High level requirements

1) Compliancy: the extent to which the security processes comply with the EU law and regulations regarding the security of civil aviation.
2) The probability of detection of ATOM system shall be at least at 80%. This means that the overall security process including procedures, personnel, lay-out and equipment should guarantee this detection level.
3) Security Perception: passenger satisfaction regarding the security level should be at least 76% of passengers scoring excellent or good.
4) Waiting Time Perception: passenger satisfaction regarding the waiting time should be at least 81% of passengers scoring excellent or good.
5) Security Personnel Friendliness: passenger satisfaction regarding the security personnel friendliness should be at least 85% of passengers scoring excellent or good.

6) There will be passengers who need an additional (regular) screening due to assumption of carrying prohibited items, possession of prohibited items or due to false alarms. The number of passengers which need this additional screening is affected by the reliability of the ATOM system.

7) The process time which airport security needs to execute screening of passengers and cabin bags using the ATOM system should not delay regular passenger flow. It means that there is no additional process time for passengers.

8) Cost: ATOM is an innovation project which will result in a prototype of an innovative multi-sensor based system. The ATOM system could contribute to the cost objective by (partly) automating the screening process which will lower the number of personnel and decrease the exploitation costs.

9) False Rejection Rate (FRR) is the extent to which the passengers are wrongly suspected by the security system of carrying prohibited items. The percentage of false rejections generated by the ATOM system shall be less than 20%.

10) False Acceptance Rate (FAR) is the extent to which the passengers are wrongly cleared by the security system. The percentage of false acceptances generated by the ATOM system shall be 0%.

4.5.8.1.2 Passive tracking radar sub-system requirements

1) With reference to a typical indoor public area, passive radar sensor detects and localises human being within a range of 100 meters

2) The bandwidth of the sources of opportunity (WiFi systems) varies between 11 and 15 MHz, so that the range resolution obtainable with a single sensor is in the order of 10 to 16 meters.

3) The passive radar should have at least a basic tracking capability.

4) Doppler resolution. If we consider a hypothetical WiFi based Passive Bistatic Radar (carrier frequency at about 2.4 GHz), an integration time of about 0.5 seconds is required to set the velocity resolution at about 1 meter per second.

5) Probability of detection is near to 0.6.

6) False alarm probability before tracking is around 10-20%.

7) Since single sensor measurements allow just the computation of target relative distance and velocity, the design of the radar receiver topology is a required in order to obtain localisation of human being targets.

4.5.8.1.3 Active tracking radar sub-system requirements

1) Robustness against interference; must not interfere with other equipment.

2) Allowed E.M. field strength is limited by health regulations. Radar approaches in other public spaces (e.g. automotive radar sensors, door openers, velocity measuring radar) will be studied on their approach for this topic.

3) the system must be able to detect and track designated (suspicious) persons and the detect and track unsuspicious persons, in order not to confuse suspicious and unsuspicious persons in a more complex scene.

4) algorithms must be developed to fuse the data from the different nodes.

5) persons must be classified from other moving objects and from the background. The most distinguishing features will be examined and chosen to build a reliable classifier.

6) Interference: low power concept; frequency/time sharing concept.

7) Health regulations: low power concept.

8) Visibility equipment: a low profile exterior is preferred in public space. This dictates preferably small nodes (max. order of few decimetres).

4.5.8.1.4 Wideband Microwave Radar in the 15–35 GHz frequency range sub-system requirements

1) Low-power emission and consumption, less impact on other RF systems in the airport
2) Immunity to interference from narrow band RF systems
3) Multipath immunity due to wide bandwidth
4) High down-range resolution, capable of precise positioning due to fine time resolution
5) Allowing use of sparse array with less antenna elements that leads to less data acquisition time, less signal processing complexity, and lighter device
6) Low-complexity transceiver architecture
7) In order to obtain a level of angular resolution comparable to the utilized microwave wavelength, the size of the array aperture must be similar to the distance of the potential target.
8) Under monochromatic condition, antenna elements spacing within the array must be less than one-half of a wavelength in order to prevent unwanted grating lobes. However, satisfying the half-wavelength criterion in practice leads to an extremely dense array for a moderate aperture size and resolution. Unfortunately, fabrication of such a dense array and its associated beamforming electronics is still unrealistic using existing microwave technology.
9) For the complete array, scanning through all transmit/receive channels would require approximately 0.18 second. With dedicated processing schemes, the system would be just enough to image fast moving objects in real-time.
10) Until now the detection and recognition of concealed weapons is commonly done by manual screening procedures which are not giving satisfactory results. This is due to the inclusion of human factors in the decision making process that causes rather high false alarm rate. The goal of research is to achieve automatic detection and recognition of concealed weapons.

4.5.8.1.5 W- band sub-system requirements

1) Passengers should be forced to enter the imaging area separately to avoid shadowing effects and unscanned body areas
2) The signal processing is carried out by using the SAR: radar sensors and target position is required
3) The concept of rotating platforms with multiple transmitters / receivers

4.5.8.2 Requirements match points and level of priority

In the next tables the level of priority between the high level requirements and the sub-system requirements match points will be identified.

	Passive tracking radar sub-system requirements						
Operational requirements	Range of passive sensor of 100 meters	Single sensor range resolution of 10 to 16 meters.	Basic tracking capability	Doppler resolution. about 1 meter per second.	Probability of detection is near to 0.6.	False alarm probability is less than 10-20%	Design of the radar receiver topology is necessary
Compliancy with the EU law and regulations.							
Detection Probability shall be at least at the current level	M		L		H	M	M
Security Perception: at least 76% of passengers scoring excellent or good.							
Waiting Time Perception: at least 81% of passengers scoring excellent or good.							
Security Personnel Friendliness: at least 85% of passengers scoring excellent or good.					M	M	
The number of passengers which need this additional screening is affected by the reliability of the ATOM system.					M	H	M
There is no additional process time for passengers.							
Cost: reduction of security cost	M	M		M			
False Rejection Rate (FRR) shall be less than 20%.	L		L		H	H	M
False Acceptance Rate (FAR) shall be 0%.							

Operational requirements	Active radar sub-system requirements							
	Robustness against interference; and may not interfere with other equipment	Allowed E.M. field strength is limited by health regulations.	the system must be able to detect and track suspicious persons	algorithms must be developed to fuse the data from the different nodes	persons must be classified from other moving objects and from the background	Interference: low power concept; frequency/time sharing concept	Health regulations: low power concept	Visibility equipment
Compliancy with the EU law and regulations.		H					M	L
Detection Probability shall be at least at the current level	H	M	L	M	M	M		
Security Perception: at least 76% of passengers scoring excellent or good.					L			L
Waiting Time Perception: at least 81% of passengers scoring excellent or good.								
Security Personnel Friendliness: at least 85% of passengers scoring excellent or good.								L
The number of passengers which need this additional screening is affected by the reliability of the ATOM system.	H		H	M	M			
There is no additional process time for passengers.								
Cost: reduction of security cost								
False Rejection Rate (FRR) shall be less than 20%.	H	M	H	M	H	M		
False Acceptance Rate (FAR) shall be 0%.	H	M	H	M	H	M		

	Wideband Microwave Radar in the 15–35 GHz frequency range sub-system									
Operational requirements	Low-power emission and consumption	Immunity to interference.	Multipath immunity	High down-range resolution	sparse array with less antenna elements	Low-complexity transceiver architecture	size of the array aperture similar to the distance of the potential target	antenna elements spacing must be less than one-half of a wavelength	scanning through all transmit/receive channels would require approximately 0.18 second	achievement of automatic detection and recognition
Compliancy with the EU law and regulations.	M									
Detection Probability shall be at least at the current level		H	H	H						H
Security Perception: at least 76% of passengers scoring excellent or good.					M	M	L	L		L
Waiting Time Perception: at least 81% of passengers scoring excellent or good.									H	
Security Personnel Friendliness: at least 85% of passengers scoring excellent or good.							L			L
The number of passengers which need this additional screening is affected by the reliability of the ATOM system.		H	H							
There is no additional process time for passengers.									H	H
Cost: reduction of security cost					H	H	H	H		H
False Rejection Rate (FRR) shall be less than 20%.		H	H	H						H
False Acceptance Rate (FAR) shall be 0%.		H	H	H						H

	W- band sub-system requirements		
Operational requirements	Passengers should be forced to enter the imaging area separately	The signal processing is carried out by using the SAR: radar sensors and target position is required	The concept of rotating platforms with multiple transmitters / receivers
Compliancy with the EU law and regulations.			
Detection Probability shall be at least at the current level		H	H
Security Perception: at least 76% of passengers scoring excellent or good.	M		
Waiting Time Perception: at least 81% of passengers scoring excellent or good.	M		
Security Personnel Friendliness: at least 85% of passengers scoring excellent or good.			
The number of passengers which need this additional screening is affected by the reliability of the ATOM system.	M	H	H
There is no additional process time for passengers.			
Cost: reduction of security cost			
False Rejection Rate (FRR) shall be less than 20%.		H	H
False Acceptance Rate (FAR) shall be 0%.		H	H

	Tracking System		**Detection system**		**Data fusion and network**		**ATOM**
Operational requirements	Passive	Active	Ultra-wideband radar	W band system	Data fusion and management	ATOM network	
Compliancy with the EU law and regulations.	☻	☻	☻	☻	☻	☻	☻
Detection Probability shall be at least at the current level	☺	☺	☺	☺	☺	-	☺
Security Perception: at least 76% of passengers scoring excellent or good.	☻	☻	☻	☻	☻	☻	☻
Waiting Time Perception: at least 81% of passengers scoring excellent or good.	☻	☻	☻	☻	☻	☻	☻
Security Personnel Friendliness: at least 85% of passengers scoring excellent or good.	☻	☻	☻	☻	☻	☻	☻
The number of passengers which need this additional screening is affected by the reliability of the ATOM system.	☺	☺	☺	☺	☺	☺	☺
There is no additional process time for passengers.	☺	☺	☺	☺	☺	☺	☺
Cost: reduction of security cost	☻	☻	☻	☻	☻	☻	☻
False Rejection Rate (FRR) shall be less than 20%.	☺	☺	☺	☻	☺	-	☺
False Acceptance Rate (FAR) shall be 0%.	☻	☻	☻	☻	☻	-	☻

Table 12 – Requirements match points

Legend:

☻ : the final system will achieve the requirement or the requirement will be validated at the end of project

☺ : the current system already achieves the requirement

4.6 Challenges and recommendations

We have found the following challenges:

Main challenges of the concept are (based on ATOM "Part B"):

- How to track suspicious persons in a crowded environment?
- The robustness of the system against interference.
- The capability of the system of not interfering with other equipments.
- Is an e.m. field strength compliant with current health regulations?

Other challenges of the concept are:

- How to fit it into the "old" system?
- Cost effectiveness for the small airports (for example: Targu Mures)?
- How to make it acceptable for all kind of end users?

We advice the following investments:

- realize test for the examination of robustness of the system against interference;
- realize test for the examination about the capability of the system of not interfering with other equipments;
- validate that the e.m. field strength compliant with current health regulations;
- prepare a cost-effectiveness analysis for the clarification of the market situation;

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