Final Project Report WP-E

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Abstract

The final report of the Sixth Sense project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, a preliminary version of the eligible costs, deviations, bills and lessons learned.

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This deliverable consists of SJU foreground.

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Publishable Summary

User errors are one of the most critical errors in a safety critical environment. In the last years Human Factors has concentrated on eliminating those - often with the result of reducing flexibility and productivity of users. And mostly also by blocking innovation. Modern technologies like eye tracking, voice recognition and gesture control were rarely taken into account. Even less a combination of those. The project 6th Sense started with the idea to improve the fault tolerance of User Interfaces by using multiple interaction sensors and comparing the result. That rough project idea cumulated in the research question: **Can the quality of the decisions a user is making, be detected by using the whole body language of a user for communicating with a machine – and thus be improved?**

In our case the user is an Air Traffic Controller (ATCO) and the environment an Air Traffic Control Tower. Specifically we intend to analyse the correlation of the change in the behaviour of an ATCO - expressed through her/his body language - to the quality of her/his decision. The result of our work may be used for an early warning for “bad” situations about to occur or decision aids for the ATCO. But before thinking about predictions we need to collect data that describe the human body language, and find/detect these patterns by smart analysis, that we want to predict in a later stage.

For the data collection we designed an experiment with an operational scenario based on Hamburg airport since its layout has sufficient complexity to bring the test personnel in difficult situations which are needed to test our hypothesis while still simple enough to assess the quality of the decisions through experts. The exercise was based on a single simulated controller working position. The test person performed a 60 minutes shift of a ground controller. During this exercise, a supervisor took observation notes and asked the participant for her/his stress level every ten minutes. The observation notes consist of a time stamp and a short description of the observation.

Sensors for reading the body language of the participant during the exercise were:

- Kinect for body movement
- Eye tracking for gaze detection
- Speech recognition
- Mouse cursor position
- Room temperature
- Heartbeat of the user

The choice of sensors was based on pre-tests regarding functionality and user comfort, general acceptance, experience, and availability.

During the workflow performance the sensor data was recorded combined with a video capture of the user interaction. The workflow was retrospectively revised by a domain expert to experts who marked bad decisions and/or bad situations arising. Eight test runs were performed in two batches to gain as much test data as possible in the available time frame to experiment with. At the end we collected about 600.000 events distributed among several datasets. The handling of the complexity and amount of data required multiple strategies for pre-processing, analysis, discussion sessions, exploration and visualization.

First problem to solve is: **How do patterns look like**? The recognition of patterns is an important part in analysing decision-making mechanisms, and it can be achieved by applying advanced outlier detection and machine learning techniques. Recent research

clarifies why the human brain makes mistakes and how the decision-making mechanisms work in reality. The decision-making tasks are now linked with sensory evidence delivered in randomly timed pulses where noise is playing a key role as a source of variability and errors.

A variety of controller errors involves perception, memory, decision-making, communication and team resource management. The classification of errors is essential to record data for the detection of trends in incident occurrence. Identifying situations where systems can fail or identifying risky strategies taken by users, makes error analysis a key component in safety management.

The topic of anomaly (outliers) detection and time series visualization are also important aspects for the analysis of time based data originated from user behaviour and from sensor data streams. Moreover, the projection of multidimensional data to a lower-dimensional visual display is a common approach to identify and visualize patterns in data.

In order to reach the goal of the 6th Sense project, we have to answer the following question: **what kind of pattern has been detected (and might be useful for the development of a prediction module)?**

At first we analysed the general performance of the users. We started with the workload estimates generated from questionnaires. Then we turned our attention to the measured sensor data. We started with simple visualizations and from that we create a list of useful and interesting metrics with different level of complexity (combined sensor data from different sources). We classified the metrics into categories. With this background we created detailed and concrete research questions that guide our analysis, visualization and exploration of data towards good predictors of the users' behaviours. This includes exploration of:

- the number of arrivals and departures per minute in relation to errors,
- increases in eye movements when the user is having periods of high workload that relates to the occurrence of negative observations,
- the relation between mouse pauses and increases in eye fixation times, the number of areas of interest visited per minute, lower heart rate variability, how the voice communications (number and speed of words spoken) is related to negative observations,
- the most preferred areas of interest by the users,
- how we might use the Kinect head pose and sound source angle variables to detect problematic time periods that might allow us to reduce the amount of data that needs to be analysed in real time.

Results: The data analysis including combined visualization methods uncovered several hints which can be used to further develop a suitable prediction algorithm. The most promising metrics and as a consequence the most promising hints were found in relations between different data streams.

- In some heart rate variability (HRV) data that if we cross check the HRV with the negative observations in the observation list, we observe that every time before an increase of severe negative observations, there is a steep descent (lower heart rate variability) on the inter-beat interval values. According to the literature HRV can be a good indicator of high stress.

- We could observe a relation between the increase in the number of words used by the air traffic controllers and the occurrence of negative observations. This seems to follow always the same pattern: there is a clear decrease in the number of words used followed by a significantly increase in the number of words spoken by the air traffic controllers.
- Reduction in mouse movement and increase in eye movement coincident with the occurrence of negative observations.
- Correlation between the users head position and negative observations that indicate promising model creation for predictions.

The results of the 6th Sense project show how important the incorporation of behavioural analysis is for the design of automated systems that are able to analyse, detect and predict unsafe situations and systems that are even useful to react or advise for better and safer actions. Our results can also be applied to the improvement of existent systems and user interfaces.

Key learnings of the work performed are:

- An analysis of decision quality through experts is difficult since the intention of the test person stays hidden. Additional self-assessment will add value in future tests.
- Analyses of sensor recordings offer infinite possibilities of combinations as well as visualisations therefrom. Further work on the existing data might produce even more significant findings

Conclusion: our test setup and process proofed right. Analytical tools and visualisations used are feasible although there are numerous other possibilities which might be even better. Due to the nature of this kind of exploratory research projects with restricted resources no statistical relevance in the found patterns is recognisable. The number of test persons was too low. However, the concrete patterns which have been found allow deriving early indications for good or bad decisions. There are good indications for positive result when more test data and more time is available for sensor permutation analysis.

Next steps: New experiments to collect more data would be the next step. In order to answer specific questions about situational awareness or task completion times we would create specific and shorter experiments focused on smaller tasks. This would also simplify measure time or speed.

Furthermore, we envision the use of graph models and prediction engines applied to behaviour analysis or to the prediction of next user actions or next best suggestions. Deep learning and agent based models are also important components for building more intelligent systems especially to incorporate cognitive features that better map the users' behaviours and the users' decision making processes. Here the inclusion of cognitive architectures could also be beneficial.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, preliminary eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

1.2 Intended readership

This document might be of interest for:

- Sixth Sense project members, including the project manager and the core team members.
- Representatives of EUROCONTROL and SJU responsible for reviewing and advising the project.
- Other researchers working on the related research projects, particularly researchers on error avoidance, new technologies and interaction methods.
- Personnel in air traffic management and other parts of the aviation sector.

1.3 Inputs from other projects

This section identifies previous work on, with a special emphasis on what is reused from other projects.

1.4 Glossary of terms

This section identifies terms not covered in one or more referenced documents and a proposed definition.

Term	Definition
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
CWP	Controller Working Position
HMI	Human Machine Interface
LH Systems	Lufthansa Systems
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SID	Sesar Innovation Days

2 Technical Project Deliverables

Project Deliverables are listed in chronological order

Number	Title	Short Description	Approval status
D1.1	Technology and Process Evaluation report	Evaluation and technology screening of interaction technologies that can possibly be used in the 6th Sense prototype	Approved
D5.1	SID Participation 2013	Poster presentation with outline of the 6th Sense Project and planned modules of the prototype	Approved
D2.1	Software Design Document	Description of the software design of the planned 6th sense module in order to evaluate the ATM scenarios and use cases of D1.1	Approved
D4.1	Verification Plan	Experimental test plan for the proof-of-concept of the 6th Sense prototype	Approved
D3.1	Prototype Availability report	Description of the 6th Sense prototype as designed in D2.1, stating the readiness of the prototype to conduct the planned experiments for the proof-of-concept	Approved
D5.2	SID Participation 2014	Poster presentation of the current status of the 6th Sense prototype with first results	Approved
D4.2	Verification Report	Report on the experimental tests, planned in D4.1, of the 6th Sense prototype including results	Submitted

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

The first public presentation of the 6th Sense project took place at the **SESAR Innovation Days 2013,** 26.-28. November 2014 in Stockholm. A poster was presented at the poster presentation session, named "*The 6th Sense of an Air Traffic Controller: Increasing Fault Tolerance of Human Machine Interfaces*". The pdf of the poster can be downloaded at http://www.fraunhofer.at/content/dam/austria/images/cgrafik/projects/6thsense/poster_6thSense_03_12_2013_small.pdf. The poster describes the overall goal of the project. A first draft of the abstract data flow of the prototype modules is presented. Connections to data bases and the complex event processing are introduced. As preliminary results, the Technology Evaluation Report, 6thSense Prototype Module Overview and Real Time Sensor Evaluation are listed.

Feedback: The feedback was quite positive and we received a lot of interesting remarks, questions and suggestions regarding additional sensors to be used, or possible future application fields. We also got some hints to already running or finalized projects of the air traffic community that could be interesting for us.

At **SESAR Innovation Days 2014,** 25th - 27th November 2014 Madrid, Spain, another poster presentation was given at the poster session, with the title ""*The Sixth Sense in Air Traffic Control - Automated error detection through sensor augmentation, while keeping the humans in the main decision loop of ATC*". See http://www.fraunhofer.at/content/dam/austria/images/cgrafik/projects/6thsense/poster_sid_2014_web.pdf for the poster download. In this poster, the preparation for the experiments is presented: The raw data event streams from multiple input devices and sensors as well as flight information data events and environmental data messages, can now be easily collected, stored and replayed for posterior analysis and observation. In addition, we can filter and correlate event streams using complex event processing, to trigger new and more meaningful events or to dynamically derive custom datasets. These datasets generated from the live raw data, are used in statistical analysis to discover patterns, to make correlations or to remove irrelevant data points. Both, the analysts and the supervisors can use our prototype as a way to understand live data, augmented with useful meaning. The framework is also prepared to allow the processing of live data (directly at the simulation time) in order to be used and processed by online learning algorithms and prediction engines, that can be constantly trained and adjusted.

At the **Airline Forum 2015,** 26.05.2015, Seeheim, Germany. Eva Eggeling gave an invited talk "Human machine interface in operation centres" at the event on the sixth sense project, the setup, aims and the preliminary results.

Feedback: The audience was very interested in the technical setup on the one hand, and on the large variety of application fields on the other hand. The audience consisted of international airline representatives and LH Systems product representatives. Especially the representatives of Canada air showed strong interest in the project results and are interested in further collaborations.

World ATM Congress, 10th - 12th March 2015 Madrid, Spain, at the Frequentis Booth
Frequentis discussed and presented the intermediate outcome of the sixth sense project and ideas of the project during the exhibition with interested customers.

3.2 Presentations/publications at other conferences/journals

At **I-Know 2014,** 11 - 19. September 2014, Graz, a poster presentation was given and a summary of the poster was published in the ACM conference Proceedings. The title was "The Sixth Sense of an Air Traffic Controller – Increasing Fault Tolerance of Human Machine Interfaces."
http://www.fraunhofer.at/content/dam/austria/images/cgrafik/projects/6thsense/Iknow_Poster_web.pdf In this publication, we describe ongoing work in progress in the project: Interaction patterns are reasoned from the combination of a recommendation and inference engine, the analysis of several graph database relationships and from multiple sensor raw data aggregations. Altogether, these techniques allow to judge about different possible meanings of the current user's interaction and cognitive state. We describe the overall structure of our software framework. An outlook is given using different machine learning techniques to make recommendations and predictions on the user's actions.

VISIGRAPP 2015, 11.-14. March 2015, Berlin, Germany, a presentation was given by Fraunhofer Austria at the "European Project Space". The European Project Space provides an opportunity for researchers and

practitioners involved in ongoing or past European research projects to present the objectives and outcomes of these projects as well as future plans regarding continuation opportunities. The project Sixth Sense was presented as ongoing work.

As a consequence of the presentation at **VISIGRAPP 2015,** we got invited to submit a **book chapter on the project Scitepress (Springer), Book Chapter.** The title is ""*Increasing Fault Tolerance in Operational Centres Using Human Sensing Technologies: Approach and Initial Results*", to be published.

The publication is focused on fault tolerance of Human Machine Interfaces and the development of a system that accepts physical user measurements as additional input. The result can be applied to multiple domains, e.g. Operational Control Centres. The experiments with professional air traffic controllers are described and the results obtained in project are discussed. Limitations and extensions for future systems are pointed out as well.

3.3 Web presence

The project web site can be found at: http://www.fraunhofer.at/SixthSenseEN

There is also a German version at http://www.fraunhofer.at/SixthSense. There is a 6th Sense short presentation at the SESAR home page at http://www.sesarju.eu/sites/default/files/documents/WPE/6th_Sense.pdf

3.4 Demonstrations

Demonstration Summary at SID 2014, 25th - 27th November 2014 Madrid, Spain

Abstract: The 6th Sense project is focused on the fault tolerance of Human Machine Interfaces in the field of air traffic control (ATC) by accepting the overall user's body language as input. Interaction patterns are reasoned from the combination of a recommendation and inference engine, the analysis of several graph database relationships and from multiple sensor raw data aggregations. Altogether, these techniques allow us to judge about different possible meanings of the current user's interaction and cognitive state. The results obtained from applying different machine learning techniques will be used to make recommendations and predictions of the user's actions.

Demonstration: The following elements are planned to be presented at the SID 2014 in the frame of the SESAR WPE - 6th Sense project:

- Video of parts of a test run based on the experimental setup.
- Experimental CWP based on following items.
    - Controller Human Machine Interface
    - Voice Recognition
    - Kinect
    - Eye-Tracker
    - Data Logging and Visualization (MySQL / Graph Database)

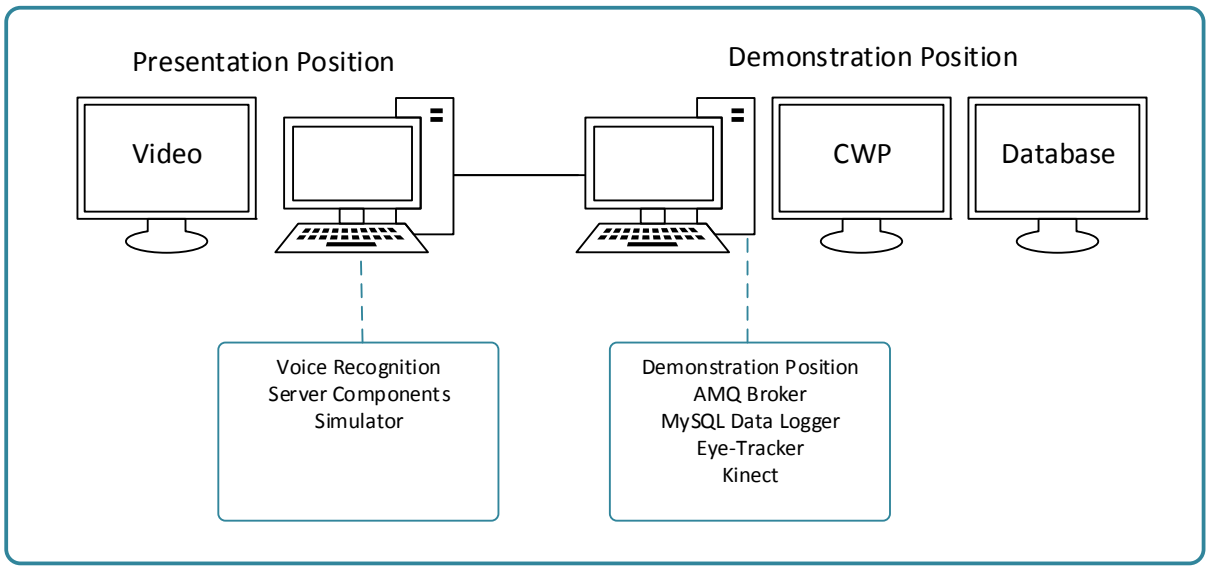

Figure 1: SID 2014 Demonstration Setup

Background information about the 6th sense project

Experimental Setup: The setup is based on, a single simulated controller working position. The experiment will concentrated on the ground traffic management. (Ground controller position)

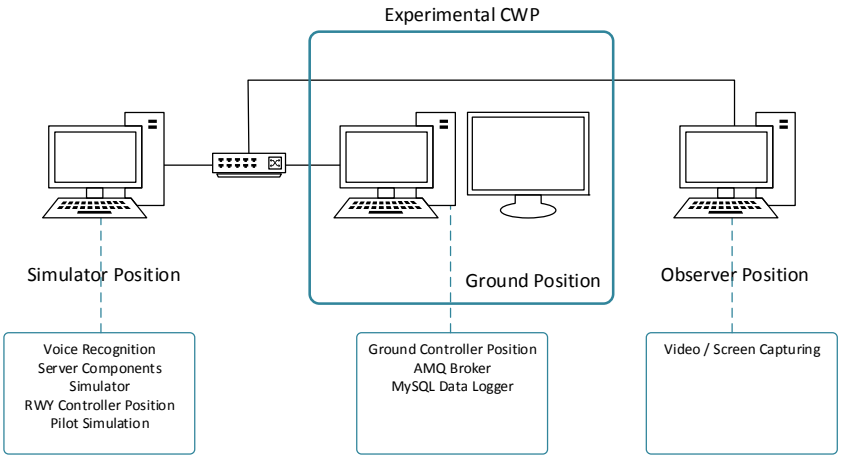

Figure 2: Experimental Setup

The Human Machine Interface (HMI): In the iCWP concept special attention has been put to the fact to achieve an integrated human machine interface as the integrated human machine interface is the component, which is directly accessed by the operator.

The introduction of a common HMI enables the operator to easily find necessary information, improves the usability of the human-machine interactions and allows coherence between the usages of different information sources. As it is the main input/output to the operators, an integrated HMI optimizes the workflow and information presentation, while reducing the stress level of the operator.

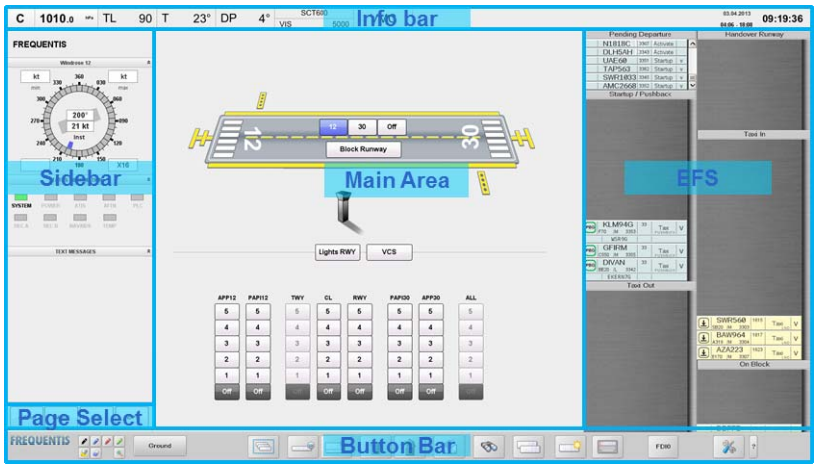

Figure 3: Components of the HMI screen

Scenario Summary: Following constraints have been used to prepare the scenario:

- Simulation prepared for approx. 45-60 min.
- Arrivals are automatically simulated until touchdown (no change of route).
- Departures are controlled until take off.
- No Runway change is foreseen within the simulation.
- Taxiway Routes can be selected by the operator.
- Simulated airport: Hamburg (EDDH)

Configurations during the experiment:

- Arrival Runway: 23
- Departure Runway: 33
- Arrivals: 31 flights
- Departures: 27 flights

Roles available within the experiment:

- Ground Controller: User
- Runway Controller: Manually Simulated
- Pseudo Pilots: Manually Simulated

Feedback SID 2014:
Following interests has been collected during the SID 2014:

- Interest in how the process of identification of patterns will take place.
- Interest on the method of collecting data.
- Interest on new possibilities to improve the failure tolerance of a controller working position with the identified data.
- Interest on the use of eye-tracking, speech recognition and Kinect as user interaction tool.
- Interest of the selection of data to be used for visualization.

Due to the fact that the experiments have not be finished until this date, it was not possible to present the final result at the SID 2014

3.5 Exploitation plans

Fraunhofer Austria has gained a lot of knowledge about the **ATM domain**, which will be very fruitful for future cooperation with partners from this application field.

The project idea and set up was a perfect platform to **improve and to apply the existing knowledge** about sensors, sensor measurements, integration and for target group specific data visualization and navigation. Also the knowledge about applied visual analytics methods could be deepened.

During the project runtime and especially at public project presentations many **other application** fields for the 6th Sense idea have been opened up, not only in the safety critical context but also for working places in general. This opens the door for consecutive research projects, national and international, or third party **funding**, which is essential for research organizations like Fraunhofer.

The feedback to our dissemination activities is very positive and at each event **new chances**, but also **new challenges** come up, that will be used for future work

Frequentis AG user centred **product line will benefit** from the experience gained within the 6th Sense project.

The outcome of the project is intended to be used in further industrial research activities with the goal of **improving future working position concepts / products** with the support of multi-sensor data.

4 Total Eligible Costs

This section is based on the Project Costs Breakdown Forms of the eligible costs incurred by project participants.

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
16.12.2015	*Del. 0.0, 0.1, 1.1,*	*82.665,30*	*Requested contribution for travel, licences, logistics etc.*	*paid*
15.10.2015	*Del. 0.2, 0.3, 2.1, 4.1, 5.1*	*119.531,91*		*paid*
17.11.2014	*Del. 0.2, 0.3, 2.1, 4.1, 5.1*	*138.609,12*		*paid*
09.10.2015	*Del. 0.6, 0.7, 0.8, 4.2, 5.2*	*57.012,48*		*billed*
	adjustment FRQ	*-5.113,03*		
GRAND TOTAL		*392.708,78*		

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
coordinator	*842,70*	*922,70*	*372.032,80*	*279.024,60*	
Frequentis	*487,1*	*545,5*	*227.368,24*	*113.684,18*	
GRAND TOTAL			*599.401,04*	*392.708,78*	

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
Unified sensor data collection was established and it worked well
Visualisation requirements to analyse possible patterns could be identified.
Analysis of sensor recordings offers infinite possibilities of combinations as well as visualizations therefrom. Future work on the existing data might produce even more significant findings
Complex event processing and the replay of experiments for the purpose of manually annotating the decisions was identified to be of great help for preparing and analysing the data streams. Here preparing also includes deriving new data streams of combined sensor data.
The interdisciplinary team from research and industry worked together very well and both teams learned a lot from each other. The researcher opened up new opportunities how innovative data visualization can support the ATC area, and the company partner shared their domain knowledge and gave important input on the practical implementation and use of new methods
The WP-E process is pleasantly slim.
What should be improved?
The exercises were too complex to analysis specific user behaviour, a more focused task-based approach would lead to results more efficiently
The number of experiments/ number of test persons for each experiment should be enlarged to enable and improve statistical interpretations.
More time has to be allocated for data pre and post processing and data analysis in relation to the other work packages
Analysis of decision quality through experts is difficult since the intention of the test persons stays hidden. Additional self-assessment will add value in future tests!
The exercises were too complex to efficiently analyse specific user behaviour, a more focused task-based approach could lead to results in a shorter amount of time.
The results of 6th Sense could have been better/more successful published in data analysis journals or conferences than in ATM.
Improvements n WP E might be considered in the information exchange within HALA. There is no contact to other researchers needed and therefore rarely ever done.

Table 4 - Project Lessons Learnt

6 References

Reference to main documentation including a full list of the project's external publications. Project deliverables should not be included here.

[1] Eva Eggeling, Nelson Silva, Volker Settgast, Theodor Zeh, Michael Poiger, Volker Grantz, Florian Grill: *The 6th Sense of an Air Traffic Controller: Increasing Fault Tolerance of Human Machine Interfaces.* – in: Poster Session of SESAR Innovation Days 2013, Stockholm; 2013

[2] Silverio da Silva, N. D.; Settgast, V.; Eggeling, E.; Grill, F. .; Zeh, T. .; Fellner, W.-D.: *Sixth Sense - Air Traffic Control Prediction Scenario Augmented by Sensors.* - in: International Conference on Knowledge Management and Knowledge Technologies (I-KNOW) (2014), S. 1 – 4, International Conference on Knowledge Management ; 2014

[3] Baris Kalayci, Nelson Silva, Volker Settgast, Eva Eggeling, Theodor Zeh, Florian Grill, Dieter Fellner: *The Sixth Sense in Air Traffic Control - Automated error detection through sensor augmentation, while keeping the humans in the main decision loop of ATC.* – in: Poster Session of SESAR Innovation Days 2014, 25th - 27th November 2014 Madrid, Spain; 2014

[4] Nelson Silva, Volker Settgast, Eva Eggeling, Torsten Ullrich, Tobias Schreck, Dieter Fellner: *Increasing Fault Tolerance in Operational Centres Using Human Sensing Technologies: Approach and Initial Results*. – to appear in: European Project Space on Computer Vision, Graphics, Optics and Photonics, Scitepress (Springer), 2015