The main S&T results can be divided into the following sections:

- Airport operational procedures (Alexandra Institute)
- Airport mobile manager concept (Alexandra Institute)
- Development of a polarization sensitive CMOS-imager and camera (Fraunhofer)
- Runway friction estimation (TUDelft)
- Water level and roughness sensor (Liwas)
- Sensor data processing (Alexandra Institute).
- Field tests (Prevas)

Each subject is described in the following sections.

Airport operational procedures and application identification (Alexandra Institute)

The activities regarding operational analysis and identification of needs were divided into three main phases:

Field and user studies: In this phase, data was collected from field studies, literature and other sources in order to enable the design of useful and working products. The operational procedures regarding runway friction estimation have been investigated by anthropological field studies. Field studies and interviews have been carried out at the following airports:

- Copenhagen Airport, Denmark
- Amsterdam Schiphol Airport, The Netherlands
- Norrköping Airport, Sweden
- Linköping Airport, Sweden
- Stockholm Arlanda Airport, Sweden
- St. John's Airport, Canada
- Frankfurt Fraport Airport, Germany

Implementation of horizontal prototypes: In this phase, prototypes of the user interfaces (also called *horizontal prototypes*) were implemented based on the data and design of phase 1. The prototypes were developed in iterations where for each iteration; feedback was collected from user tests with airport personnel. This way, the concepts and designs were fine-tuned and validated before the implementation of the underlying functionality began.

Implementation of fully functional applications: In this phase, the functionality of the applications was implemented, and the data communication infrastructure was developed.

The development was governed by the development standard DO-278 (assurance level 5), which is typically required for critical software operating at airports. The standard puts process requirements on management of requirements, design, implementation, verification and configurations. A software plan fulfilling these process requirements has been developed and is documented in *WP7-010: Software Plan*.

Target applications.

Based on the results of the project have 3 different target applications been identified. This section presents the application concepts that the end-user applications of Airfield Monitor were developed upon, and a short justification for the choice of these concepts. Details are provided in *WP7-003: Field Studies and End-User Applications*.

The result of the field studies on existing communication means in airports is the choice of three application

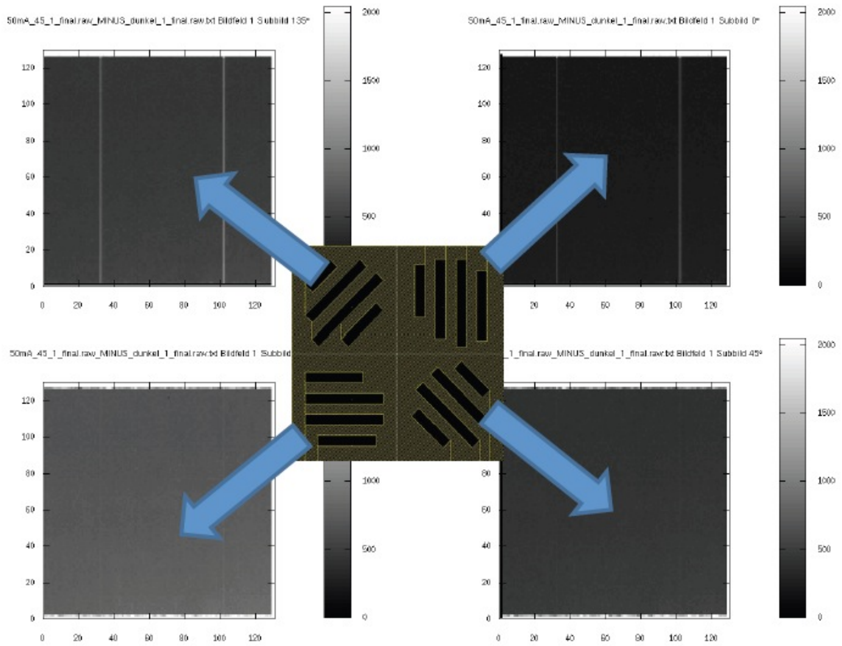
- *Mobile Manager*–allow the Airside Operations Manager (AOM) to be more mobile by providing data and functionality in the field.
- *Friction Alarm*–provide airside operations staff with continuously updated data from sensors to support decisions on when to perform friction runs and close runways.
- *Snow Fleet Focus*–provide deicing and snow cleaning staff with detailed information about the distribution and thickness of the contamination, allowing them to focus their work where it's most needed and to save chemicals.

The main purpose of the two first applications is to assist the AO Min making decisions about the runways, which affect the capacity of the airport. The reason for this focus is that one of the main findings of the field study has been that the bigger airports have their main focus on keeping capacity high, also under winter conditions, while also keeping secure operations. When dealing with keeping capacity high, the AOM draws on a lot of information sources, and discusses decisions with his colleagues. Doing this he isn't always located in the command central, but is often on the airside, while still in need of the same information. This need gets urgent under bad weather conditions, when one AOM is located on the airside and the other in the command central and they have to communicate in order to make decisions based on the information available to them. Another reason for the choice of these concepts is that although this study has revealed differences in the needs of big and small airports, both of them would find at least the Mobile Manager application useful in their daily routines.

Concerning the Friction Alarm concept and the various data available in the Mobile Manager concept, the reason for focusing on this is that the airports are hoping for more precise measuring methods. They would like to have more precise measuring of friction and more precise measuring of contaminations than the ones used today. Adding to that they also talk a lot about having a system that can provide them with new data on friction and contamination, but without having to make a friction run. To keep the capacity high it is important to disturb the runway as little as possible, meaning to sweep it as little as possible and to make as few friction runs as possible. Another important issue related to the need for precise data is related to the fact that there at the moment isn't one approved method for measuring friction that the airport can rely on, and that the method in use with a friction wheel doesn't always produce reliable data –sometimes due to wet contaminants and sometimes due to a slightly wrong tyre-pressure. Concerning the categorization of measuring contaminants and percentage covered, the airports are quite happy with the available categories in the SNOWTAM, but they are split concerning the measuring method which is eyes/hands/feet and accordingly very subjective. On the one hand they can't imagine an automatic method as reliable as their own personal measurements today; but they also question the reliability of some of their colleagues' measurements –due to the subjectivity of them.

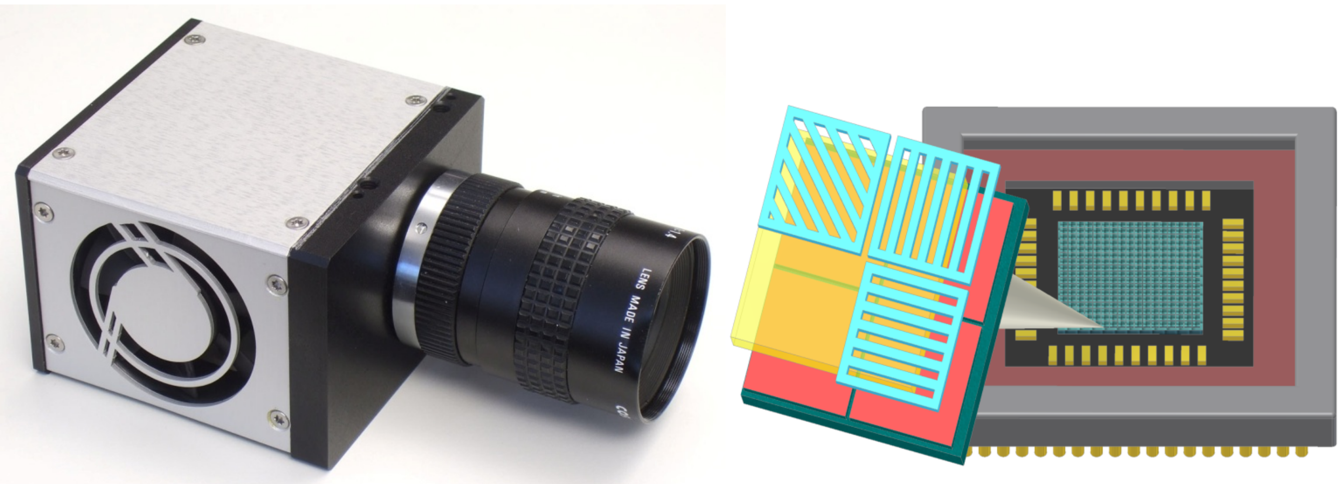
Development of a polarization sensitive CMOS-imager chip and camera (Fraunhofer)

The development of the camera incorporated several tasks, the basic polarization sensitive CCD-chip itself and the operational system to be fitted into the airport structure. A proposal for installation of camera and illumination has been worked out. A camera and an illumination system for positioning in airports have been defined. All main camera parameters such as the field of view, pixel size and camera lens parameters have been calculated. Estimation of the power budget shows that the power budget is sufficient for measurements even under strong fog. Under very strong fog conditions is the power budget not sufficient for reliable operation of the camera. The calculations have been verified using a laboratory measurement setup and a clear distinction between ice, water and concrete has been shown to be possible.



Principle of 4 sub-images at 0˚, 45˚,90˚,135˚.

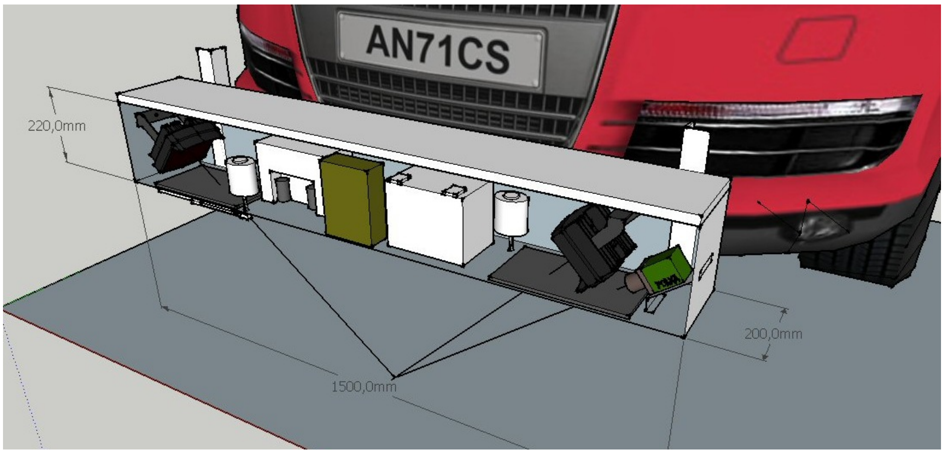
During the work on concept development the gathered information on legislative requirements for IR lighting in/on the runway identified potential problems regarding the use of high-power IR-illumination on masts near the runway and therefore the developed concept with stationary illumination systems of airfields has been paused. This was due to the potential installation costs, the ICAO regulations and the potential eye safety issue regarding use of IR-lasers for illumination. Focus has subsequently been on a small system of IR lamps mounted onto the vehicle together with the camera system / sensor itself. The development of the image sensor chip has been initiated. Unfortunately, the foundry, located in Israel, made a severe mistake in processing the chip and it took much effort in sensor evaluation to discover and localize the error. Finally, the chip was reprocessed and characterized in the lab. It worked functionally as expected but showed some issues in wavelength dependent pixel crosstalk that would have to be fixed before implementing the device into a product.



Polarization camera prototype and drawing of the sensor chip itself.

The camera is capable of determining the 4 stokes parameters S1-S4, determining the degree of optical polarization.

The work on the camera prototype itself was finished and the camera was built into a robust housing. The whole camera was finally mounted onto a vehicle together with the illumination system and has been used for

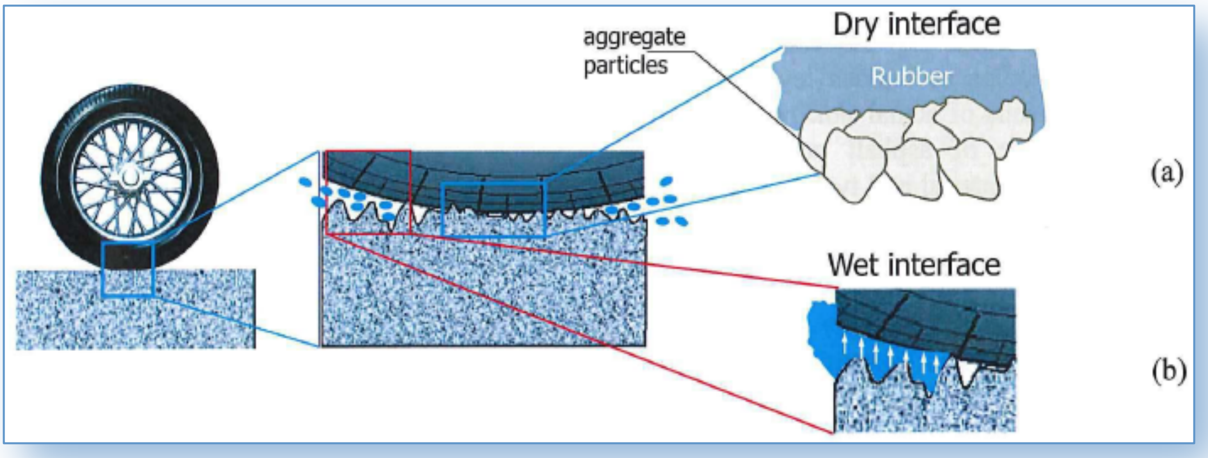


Principle of camera mounting on a vehicle. All sensors integrated into a single housing.


Mounting of IR-source and camera during field tests.

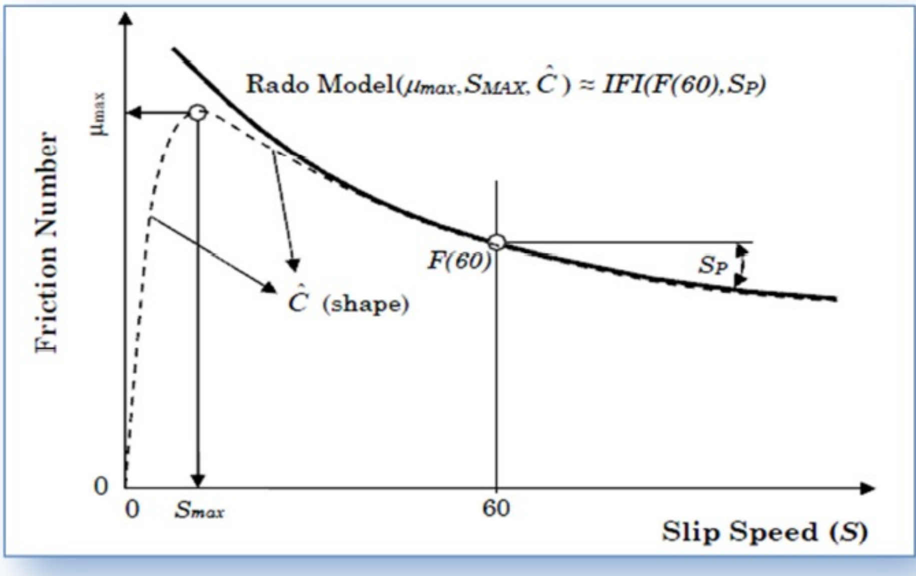
Runway friction estimation (TUDelft)

The goal of this task is the determination of the skid resistance of runway surfaces on the basis of contact measurements via commonly available continuous friction measuring equipment. The texture characteristics of the surfaces have also been examined. Friction is defined and the factors that affect skid resistance are studied. Moreover, the friction mechanisms are explained in an attempt to thoroughly understand the complexity arising from the tire-pavement interaction.



Factors influencing skid resistance at the tire-pavement interface: (a) tire-pavement interaction, (b) moist hydrodynamic stresses at the tire-pavement interface.

The data collected has been used to interrelate the different runway surface climatic conditions (RSCCs) as can be identified by the Airfield Monitor sensor and camera with skid resistance. For this reason, it is important that the skid resistance and texture measurements are performed in conjunction with the Airfield Monitor System. The influence of various surface conditions, e.g. ice vs. snow or slush, on the available friction, can be quantified by means of the Rado-IFI model at different speeds. There are three important parameters that constitute the equation, i.e. μmax, Smax, and C. An extensive literature search and evaluation of all scientific aspects regarding skid resistance has been performed by TU Delft. Several documents were reviewed and different models were examined so as to determine the one that can provide the most accurate prediction of friction under different Runway Surface Climatic Conditions (RSCC).



The IFI and Rado-IFI models.

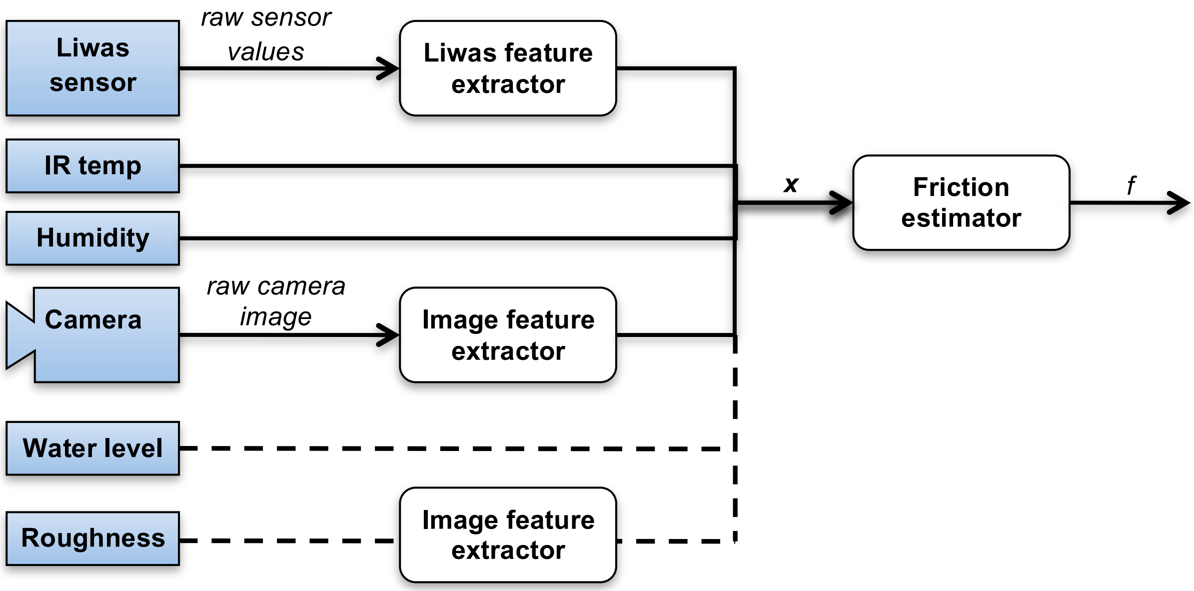
The Rado-IFI model was chosen to evaluate friction as it was proven to be capable of incorporating the various RSCCs while the initial idea of using the International Runway Friction Index was abandoned as less amendable to the incorporation of RSCCs. Also, although the IRFI is a very promising index for reporting the friction characteristics of airport movement areas, it is not a universally applied or accepted index at airports around the world. The Rado-IFI model, known also as the logarithmic friction model, was developed to complement the PIARC model by incorporating the first "leg" of the friction curve where the friction number increases to a maximum. Calibration of the model versus the indications of the Airfield Monitor sensors and cameras for various RSCCs will take place as soon as they are operational. The missing work to be done by SME-partner prototype optical sensor could not be integrated into the test program. It was hoped than a fast replacement of Amfitech with a new SME-partner could have been identified. This resulted in a delay of the deliverables D3.1 and D3.2. Starting measurements, without parallel measurements with the prototype sensor from Liwas, meant that the measurements were to be repeated when such an operative sensor was available through the new partner. Most significant results are the implementation of Rado-IFI model whenever varying slip skid resistance measurements were carried out and parameter determination algorithm/software.

Water level and roughness sensor (Liwas)

The development of a water level sensor has been described on a theoretical level, taking the wavelength dependent optical properties of water and ice into consideration. Due to the problems encountered in the project has it unfortunately not been possible to realize the planned prototypes. The theoretical analysis showed that a water (or for any other liquid substance) level sensor is very likely to be based on the optical platform, by careful selection of the optical wavelengths. It seems further possible to change the optical wavelengths to below 1000 nm, in order to lower the price of the system considerably, both with respect to detectors but also with respect to optical light sources. A phase-locked-loop detecting method is proposed to enhance the signal-to-noise ratio of the detected signal. It seems further possible to use the low wavelength area for the polarization sensing, so that a full system is based on cheaper optical components.

An initial review of basic optical techniques suitable for optical roughness sensing has been performed. Of these do white-light-interferometry (WLI) and speckle correlation seem very promising, but both require extensive R&D activity not possible to incorporate into the present Airfield Monitor project. Both the white light interferometry and the speckle correlation schemes are believed to be able to be used in roughness sensors for wet surfaces, but both schemes require basic research and will heavily depend on high-speed image processing and fringe analysis. This is outside the frames of the project, but it is the hope that this novel approach can be investigated in a future project.

The integration of these novel sensors, once developed, into the infrastructure of the developed sensor platform is not considered a problem as the addition of additional sensors is foreseen in the software structure developed. This is illustrated in the picture below.



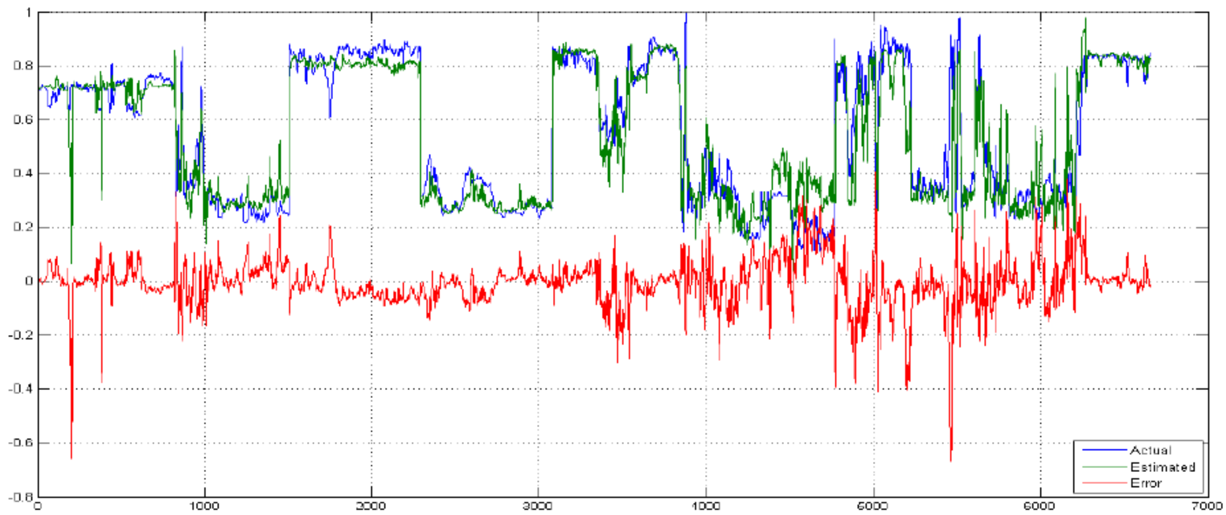
Data flow of final algorithm. From deliverable D6.1, updated with water level and roughness sensor (dashed lines). Sharp-cornered boxes indicate physical sensors, rounded boxes indicate a processing algorithm and arrows indicate data flow.

Sensor data processing (Alexandra Institute)

Two models have been investigated, the SVM (Support Vector Machine ensemble) and the FGRM (Filtered Gaussian Regression model). The numbers in general show that out of the two models, the SVM ensemble performs best on our validation data, but as the FGRM model uses only two of the available sensor signals are there good reasons to believe that if the best properties of the two models were combined in a single model that uses all available features, we could achieve considerably better results. Unfortunately, time constraints prevented us from developing such a model. For a system to be used in real-world operation, work remains in collecting data from all the different conditions that could possibly arise in a real setting (metrological conditions, surface types etc.) .

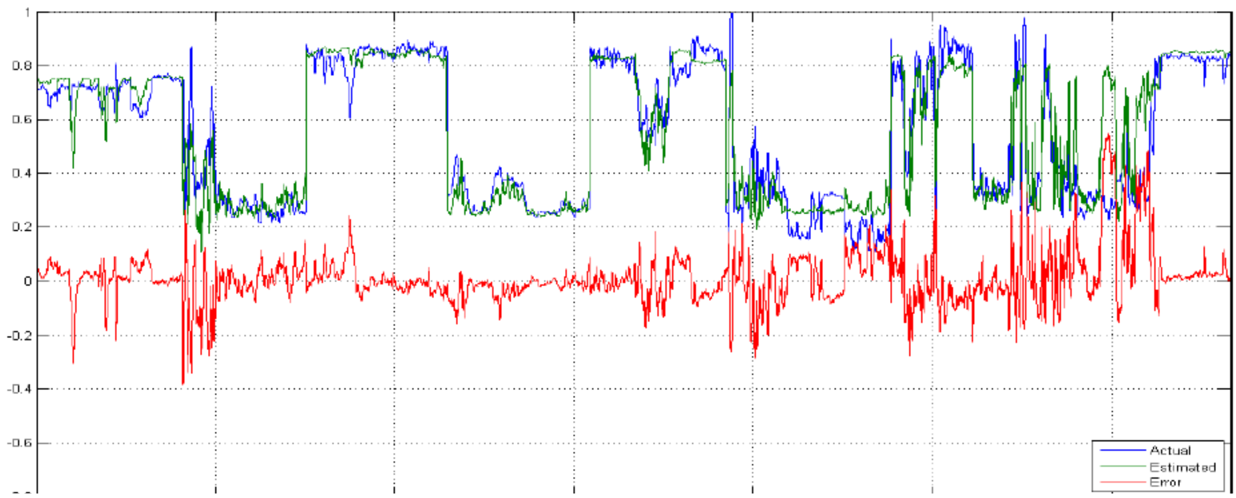
Validation results for Support Vector Machine (SVM) ensemble.

Validation Set	RSME	Worst Error	Worst Section Underestimate	Worst Section Overestimate
1	0.091	-0.67	-0.017 (0.610 - 0.627)	0.013 (0.428 - 0.414)
2	0.038	-0.34	-0.033 (0.817 - 0.850)	0.018 (0.827 – 0.809)



Validation results for the Filtered Gaussian Regression Model (FGRM) ensemble.

Validation Set	RSME	Worst Error	Worst Section Underestimate	Worst Section Overestimate
1	0.100	0.55	-0.009 (0.580 - 0.589)	0.061 (0.546 - 0.485)
2	0.053	-0.39	-0.008 (0.796 - 0.850)	0.034 (0.848 - 0.814)

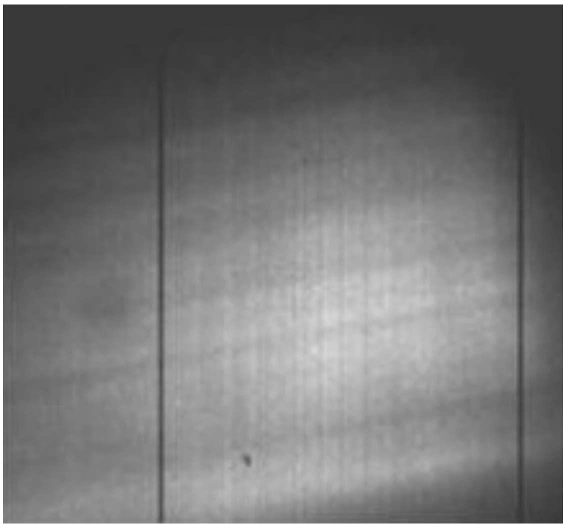


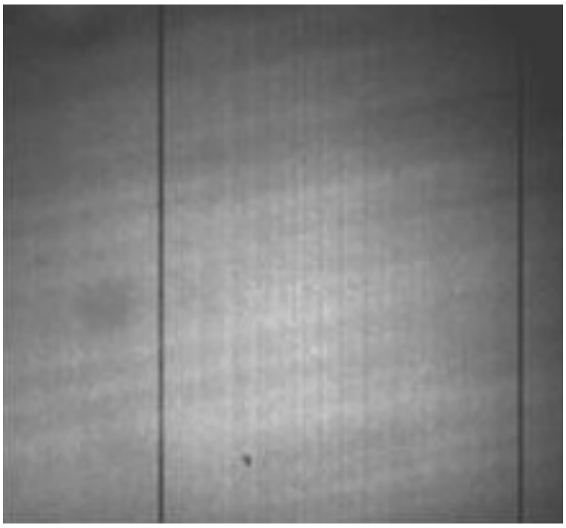
Considering the RSME and worst absolute error, which both are measurements of the performance on individual samples, the RSME in the order of 0.1 and worst absolute error in the order of 0.5 are not acceptable for real-world operation. On the other hand, the section errors around 0.03 are in the same order that we would expect for the differences between different types existing mechanical devices. Hence, for airports only using the section averages for their operation, we believe that the SVM model could be acceptable as it is. Finally, it must be strongly emphasized that these results are only valid for the conditions under which our data was collected.

Field tests

Field tests have been carried out in Aarhus Airport, Denmark. The prototype camera from Fraunhofer IIS has been mounted on the vehicle at Aarhus airport and measurements have been taken and used as input to the data processing. The interface between the camera and the recording unit showed to be a major technical task, but was solved in the end. It has thus possible to perform correlated measurements of both skiddometer data, the data from the optical sensor as well as from the polarization camera.

The pictures below show polarization pictures taken with the prototype camera developed by Fraunhofer IIS as part of the project. The values listed below refer to the reference friction index measurement by the skiddometer as well as the individual polarizing-components (Stokes vectors S0, S1, S2). The inserted lines in the last photos are used in the data processing algorithm.





Examples of measured friction data are shown above under signal processing and the testing of the SVM and FGRM models.