Final Report on Signal and Image Processing for Road Condition Classification

Reference numbers:

Signal processing (ARCANA):
Vinnova: Dnr: 98-07003
AerotechTelub: 95241-49315

Image processing (MARCONI):
Högskolan: Obj. Nr. 32150512
Vägverket: Dnr: AL90 98:9694
AerotechTelub: 95241-49801

The projects and this report are carried out in cooperation between AerotechTelub and Dalarna University. The project manager for the both projects has been Lars Forslöf, AerotechTelub AB.

Abstract

MARCONI and ARCANA are two systems for classifying road conditions by using cameras and microphones respectively. MARCONI determines the road condition from an image of the road. ARCANA uses a similar method to classify the road condition by analysing the characteristic sound signals from passing cars on different road conditions.

The systems have been operational during the winter season 2000/2001 in addition to manual observations of the road. The results from the evaluation are very satisfying (see the table below) especially for icy and wet road conditions. MARCONI and the Hybrid also performed well in classifying snowy roads.

		Network Performance (correct classification)				
		Wet	Ice	Snow	Dry	CV-Threshold
System	MARCONI	99%	85%	81%	57%	0.2
	ARCANA	97%	98%	0%	6%	0
	Hybrid	88%	99%	97%	30%	0

CV-Threshold is a confidence value acting as a filter to remove faulty classifications.
By compiling a larger database for all road classification the results will be improved.

Contents

1 Summary

This report summarizes the result from two projects in co-operation between AerotechTelub and Dalarna University. External sponsors have been the Swedish National Road Administration (SNRA), Nutek, and Transportcentrum.

The project results point to the potential use of intelligent audio/visual (AV) sensors with an accuracy of 90% correct classification of road conditions. This is a revolution of the branch, especially as the sensors also are non-contact and flexible in their use.

As a result of the projects, the technology is in a phase where suitable technical components should be offered for use in Road Weather Inforomation Systems (RWIS). We now know what performance could be achieved for which price.

There is a need for focused product development and marketing in order to develop and implement the full potential for an audio-visual sensor system. There is also more applied research to be done - to eliminate problems and limitations, further enhance the classification, and facilitate the installation of new sensors systems.

The concluded suggestion is that two new projects should be launched:

1) One project with a focus on development and implementation of a number of sensors in SNRA’s Road Weather Information System. The sensor system should be integrated in an embedded solution, able to work “stand-alone” via an RS-232 interface. The hardware components need to satisfy both economical and functional requirements.

2) One continued research project to build up a genuine database of images and sounds with manual documentation should be created. Data should be used to trim the algorithms for all road conditions and for more flexible use. The use of Infrared light for image analysis should be evaluated and advice should be given on whether image processing is a feasible way to continue.

Furthermore, an independent partner should perform an evaluation of the project results. The study should delve into both the commercial aspects of a continued development and the relevance of continued technical research work.

In addition, an independent study of AV equipment should be done. This is an area with many possible choices affecting the quality, function, and price. The lack of expertise in AV components for ARCANA/MARCONI has seemed to cause some problems. A professional within the AV market should do this study with the functional demands put up from these projects.

The unfortunate lack of winter conditions during the winter 1999/2000 provided a very limited amount of data from ice and snow conditions, which seriously affected the final trials during 2000/2001. For upcoming trials, the suggestion is to place the trials in northern Sweden to ensure real winter conditions.

One “soft” benefit to follow up with this project should be the way of successful co-operation between the University and the Company.

Project results summary

Prototypes for both MARCONI and ARCANA have been in operation and completely automated during the past 2000/2001 winter. Extensive manual observations of road conditions have enabled a comprehensive study of how these systems will be expected to perform in future operation.

As the prototype lay on a high volume highway, essentially no cases of snow-tracked road or snow-covered conditions were observed. Similarly, severely icy roads and partially snow-covered conditions were much less common than dry and wet conditions. Although a final system should be trained with approximately 200 examples per road condition class, enough data was available for a serious examination of the system.

Performance in the validation set for MARCONI proved extremely reliable, with performance over 90% correct for all classes. This proves that if given a high quality and well representative road image, MARCONI can make extremely accurate classifications. Performance with images from the entire winter season, a much more realistic condition, was still very good with near or above 80% correct for all classes except dry.

Performance for the ARCANA network was not as high as expected but outstanding for the most important classes – Wet and Ice. Previous work [1] indicated performance in the 90% range for all classes, but this was achieved only for wet and icy road conditions. The cause of failure could possibly be due to systematic noise in the signals, but is more likely due to difficulties for ARCANA to recognize borderline classes such and damp, snow cloud, and slush.

Of most interest is that combining MARCONI and ARCANA to a hybrid system achieves 90+% results for all classes except dry. Dry performance can be boosted by including other RWIS data such as humidity and precipitation since the largest error stems from dry roads being classified as wet.

		Network Performance (correct classification)					
		Wet	Ice	Snow	Dry		CV-Threshold
System	MARCONI	99%	85%	81%	57%		0.2
	ARCANA	97%	98%	0%	6%		0
	Hybrid	88%	99%	97%	30%		0

Presently, the largest hindrance is compiling a database with 200 or more high-quality examples per road condition. Networks trained with such a database can then be implemented directly into the existing prototype. Results from the prototype have illustrated that 90+% correct classification is obtainable, even in real-world and real-time conditions. For further investigations of the results see section 4.

2 Introduction

2.1 Definition

The acronyms for the two projects are **ARCANA,** *Acoustic Road Condition ANAlysis* and **MARCONI,** for *MAchine Recognition of road Condition using Optical Neural Informatics*. Both project names were invented by Andreas Kuehnle and have been used throughout the R&D phase. As there are other occupiers for the same names, both ARCANA and MARCONI need to be changed for a final product.

Concerning road condition classes (RCC), the system solution for both ARCANA and MARCONI was designed to handle following 5 classes: wet, dry, snow, ice, and tracks (MARCONI exclusively).

2.2 Background

Signal processing for road condition classification was attempted by Enator Telub on a winter road maintenance vehicle already in 1994 – see [1] and [2].

ARCANA was launched in late 1998 after AerotechTelub (at that time Enator Telub) was granted partial financing from Nutek. Transportcentrum in Borlange was willing to be a co-financer and the main work was to be done in a co-operation between Dalarna University and AerotechTelub. Other participants in the early phases were Allogg and Tuben Teknik, for their specific competence and knowledge from other R&D projects. Initially the SNRA would participate with financing for field trials in Blekninge/Säkereken, but this participation was later cancelled.

MARCONI was financed as an R&D project by the SNRA, where Dalarna University had applied for a project. Andreas Kuehnle had completed promising preparatory work during 1997 and there was a great opportunity to share intellectual, technical, and practical experiences with ARCANA and in co-operation with AerotechTelub.

AerotechTelub became the project manager for both project and their project manager was Lars Forslöf. Main software developers in the project were Hans Jones and Daniel Heden under supervision by Patrik Jonsson.

After Andreas Kuehnle left Dalarna University, Kevin McFall continued developing the artificial neural network (ANN) intelligence and analysis algorithms.

2.3 Purpose

As the title of the report explains, intelligent sensors for classifying road condition have been developed. Such sensors will provide very important content to operations and traffic safety during wintertime. Winter Maintenance Systems, Intelligent Transportation Systems, and Road Transport Telematics would be able reach a far more efficient level.

Today's computing power and AV electronics are enabling a development for the civil sector. The technology is not new, but has traditionally been implemented only by the military (as for detecting and classifying submarines) due to costs for development and components. In recent years, voice recognition applications (as in automatic telephone desks and cellular phones) and inspection detectors for the industrial and mechanical sector have been developed. These applications typically have strong commercial power or high costs for malfunctions, as well as representing a quite straightforward analysis.

The basis for the RCC analysis is the use of ANN based on audio and visual data. A trained human can relate a certain appearance of the road or a tire sound to a specific road condition. ANNs can be used in the same way, first to be trained with data on defined road conditions and then to detect conditions based on a road image or a sound from a passing car.

One huge potential is also that an ANN can give more descriptive information than a traditional binary sensor. A road can often consist of several road conditions (as both ice an snow or wet and snow). Intelligent AV-sensors can be able to automatically transfer this information to the RWIS.

2.4 Goal

The goal has been to provide an evaluation from field trials with the signal and image processing for road condition classification. This goal also includes a deep technical investigation of research papers from the analysing technology, and a description of the design of the hardware and software systems.

Concerning MARCONI, an investigation about the system's ability to provide prognosis should be reported.

This final report should give the guidelines for the continuation or discontinuation of projects related to the technology of current interest.

2.5 Limitations

The project has not covered:

- Measurements of traffic or noise emissions. This is technically possible in ARCANA and the technology is described in Appendix 2.
- Implementations of road condition prognosis in field trials (MARCONI)
- Trials with illuminated road at night time (MARCONI)

3 General information about the projects

This chapter briefly describes the completed work and technologies involved. Technical reports and appendices are referred to for more detailed technical descriptions.

3.1 Common

The work has consisted of research, development, integration, trials, and evaluation.

- Dalarna University has been responsible for research and evaluation activities quite apart from other activities.
- AerotechTelub has, except from the system development, been responsible for all project management which at times included many practical issues as extra data collection, temporary personnel, building plans/permissions as well as the administrative and reporting role.

The project progress has been generic and dependent on the two major participants steps, with an overall satisfactory performance from both parts. Figure 3.1 below shows roughly the different blocks of work and their dependency.

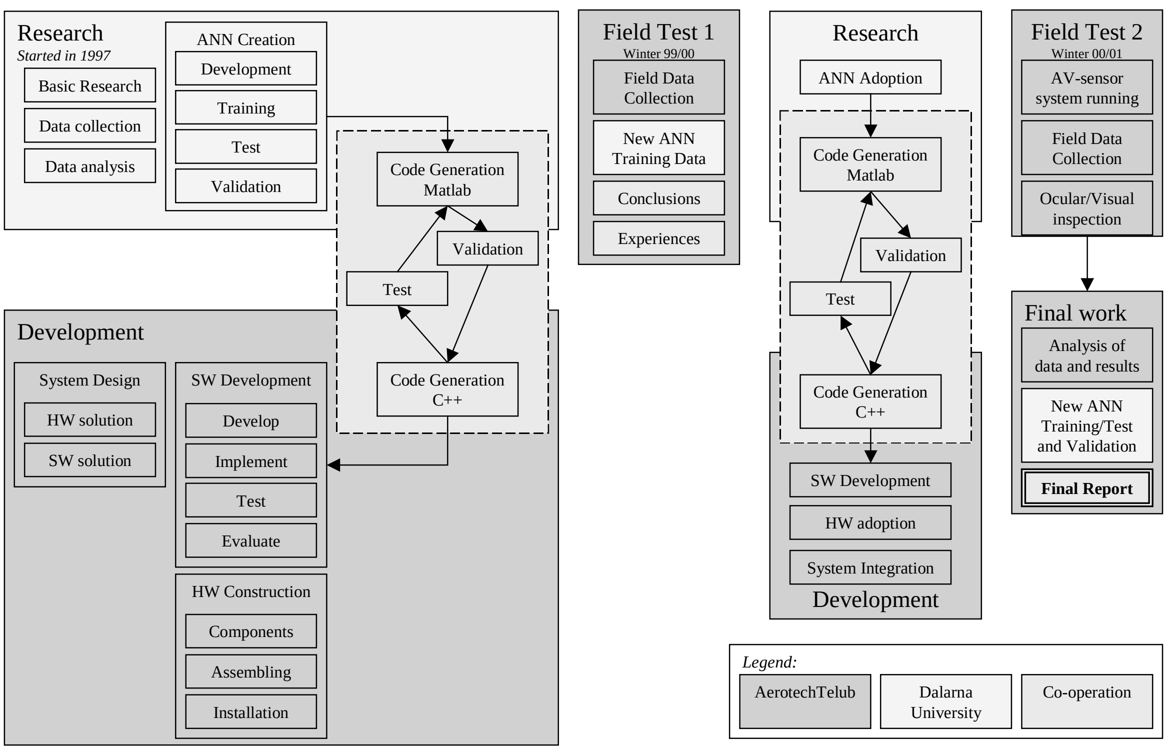

Fig. 3.1 Overview project activities

Principally, both MARCONI and ARCANA have been developed in the same way: data has been collected, algorithms developed, and system functions implemented and tested.

Data was initially sampled manually – for ***ARCANA*** with a DAT-recorder and a microphone and for ***MARCONI*** with a video camera. The sampling personnel visually noted the road condition corresponding to the data files. After the neural network was designed, the first data samples were used to train, test, and validate the systems.

One unfortunate factor was the lack of winter conditions during the first winter (1999/2000) for field trials. This caused a very limited amount of data from ice and snow, which seriously affected the final trials during 2000/2001. For upcoming trials the suggestion is to place the trials farther north to ensure real winter conditions.

The development work consisted of both hardware and software construction. Considering the demands of performance for calculations and the need for rapid development, the PC-platform was the only choice. Hardware for both image and sound capture was easy to realize and Windows functions for images and signals could be utilized. The Windows environment facilitated the transformation of code algorithms from MATLAB to C++.

As a software platform, the MS2000 developed by AerotechTelub on behalf of the SNRA was used. The MS2000 was planned to become the high-end RWIS-station for future ITS-applications. The MS2000 with a PC has shown not to be a suitable choice for the field, due to its sensitivity for roadside use and high cost. However, for R&D purposes in ARCANA and MARCONI it has been shown to work excellently.

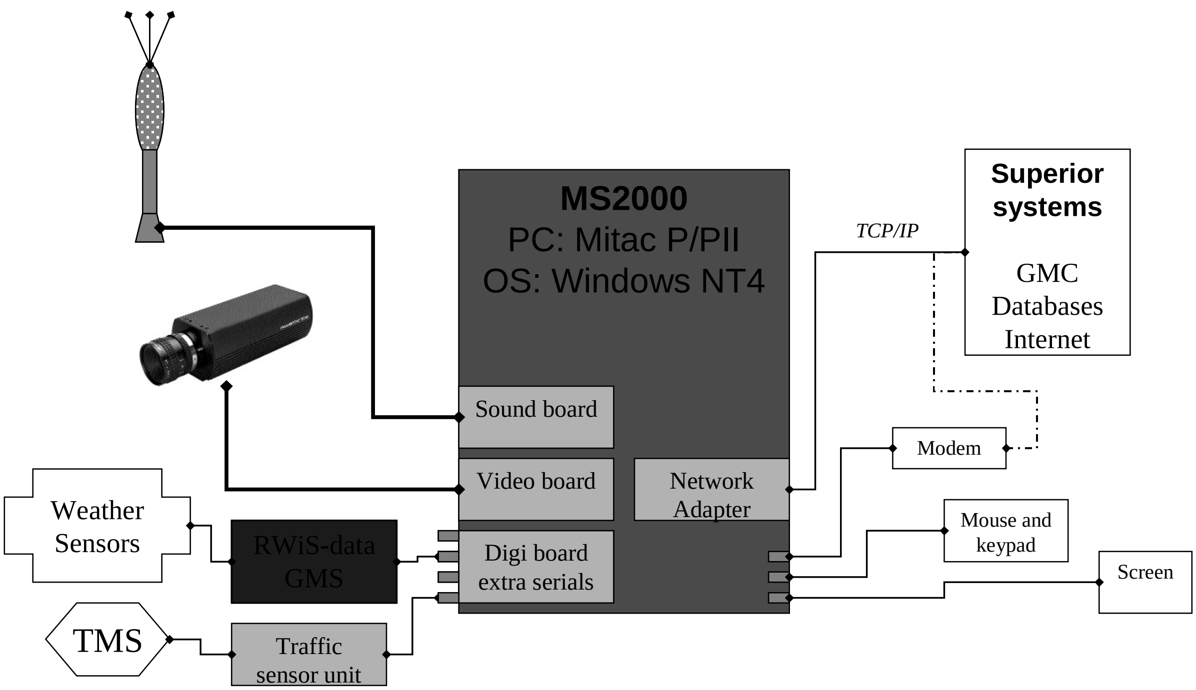

Fig. 3.2 System overview

3.2 ANN kernel - from MATLAB to C++

The MATLAB analysis functions made by the researchers must be converted to a standard computer language. C++ was convenient, as the MS2000 was built mainly with C++. The C++ code is efficient and reliable and allows the possibility of using software components from different hardware manufacturers. Unfortunately it was not possible to convert the MATLAB code to C++ automatically or compile it with special MATLAB libraries. All neural network routines had to be rewritten in C++ in order to complete the implementation in MS2000.

3.3 Integration of AV components in MS2000

Here two alternatives were considered:

- Build hardware communication from scratch in C++
- Use Windows API and multimedia functions as DirectX

Extensive use of C++ standard libraries would create the most stable solution with the possibility to port the software to platforms such as Linux. Software modules for the specific hardware components would have to be developed depending on the platform and hardware used.

Using almost only Windows API or other Windows libraries would theoretically create software more independent of the PC hardware components. Drawbacks with such a solution are typical Microsoft Windows related problems with drivers and would not ease a porting to other platforms. Also the change of video or sound boards would cause problems. A common system design was created for both ARCANA and MARCONI as below:

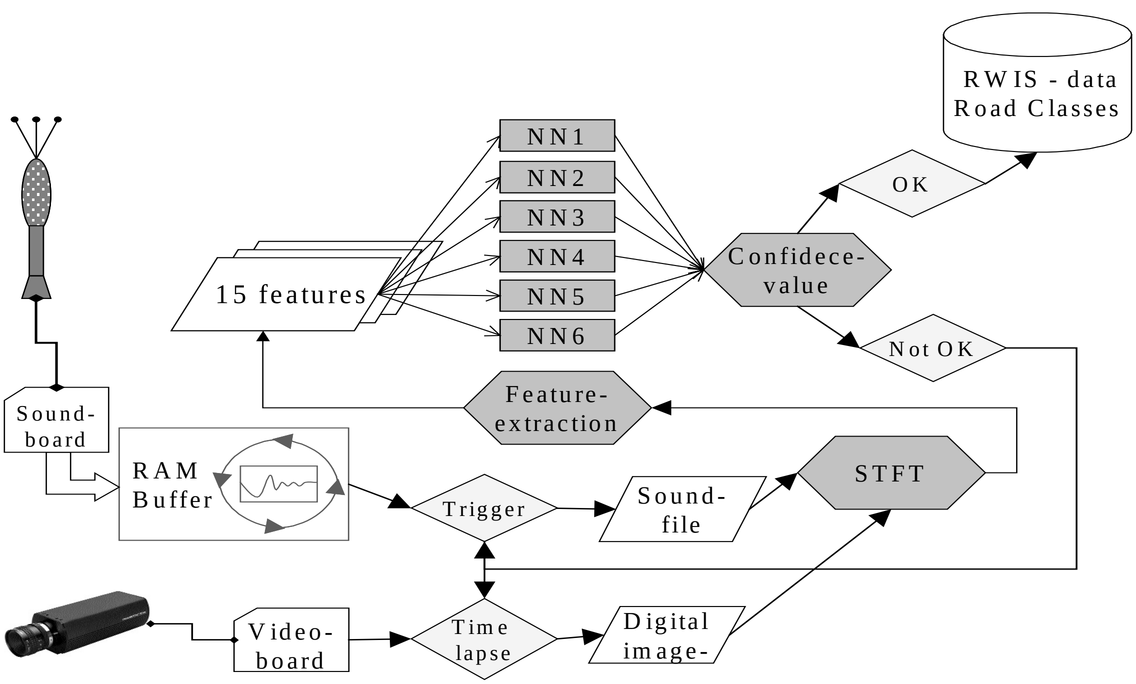

Fig.3.3 The system design for ARCANA and Marconi

For more information about the MS2000, please contact AerotechTelub.

3.3.1 MARCONI integration

In MARCONI, the software solution was created for a Matrox Meteor II frame grabber card. This is considered a qualitative and stable board supporting software development with its own Matrox Imaging Library (MIL) and ActiveMIL. MIL is a high-level programming library with an extensive set of optimized functions for image capture, transfer, processing (eg. point-to-point, statistics, filtering, geometric transforms, FFT), pattern matching, graphics, and display.

ActiveMIL is a collection of ActiveX controls (OCXs) for managing image capture, transfer, processing, analysis, and display. ActiveMIL fully integrates into Microsoft C++ rapid application development (RAD) environments.

In MARCONI, MIL is used only for the purpose of grabbing the picture and to write the data to disc. This can be done on a time-based interval with no specific trigger function. Other functions are written in C++ code and integrated with the MS2000 where the analysis is done. The results are written to the database together with ordinary RWIS-data.

The camera works completely independent of the software. Camera quality must be equivalent to SVHS although in grayscale images are sufficient. Laboratory tests have shown that color images do not yield significantly better results. The camera used is a SONY SPT-M124 with 1/3" interline transfer type CCD.

To achieve a suitable image the camera needs to be aimed directly at the road surface and not into the sun. In order to concentrate analysis on the interesting area and to minimize processing, a software for masking the image was developed. Here is an example how this works:

Fig. 2a Unmasked image

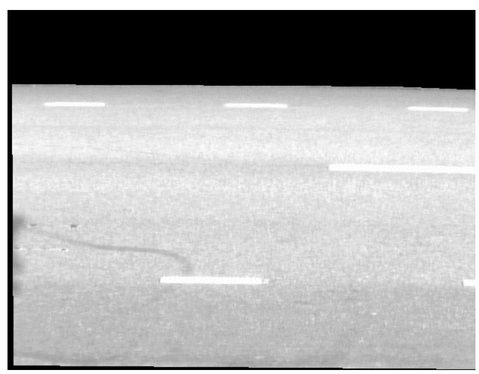

Fig. 2b Masked image

Along with automatic analysis that requires an uncompressed image, it is fully possible for the MS2000 to compress and save images or send them to traffic central or the Internet.

3.3.2 ARCANA integration

A first test with an inexpensive standard outdoor microphone (Shure M58) showed that the microphone broke after a few weeks, although sheltered in an isolated tube. This resulted in the trial of two borrowed "rugged" microphone systems from Bruel & Kjaer and Larsen/Davis. For the final field trials in the winter 2000/2001 two Larsen/Davis systems were chosen, mainly due to their built-in amplifier.

The microphone was connected to a soundboard via a simple amplifier (Midiman Audio Buddy), which was mounted inside a heated weather station. The Midiman amplifier has been a source of problems, it is not a rugged component and has a sensitive amplification and power supply. The Soundboard used was a Digital Audio Labs Card deluxe with 8-24 kbit resolution and 8-96 kHz sampling rate. This card has both analog (TRS) and gold tipped S/PDIF digital (RCA) in/out. Card deluxe supports DirectX.

Several soundboards were tested and a standard Creative Sound-Blaster was used during the development and seemed to work better with Windows NT. The SBs minor technical specification compared to professional soundboards was considered not to be critical for the system's functionality in a future development.

For the sound code in ARCANA, standard multimedia waveform and auxiliary audio services of the Microsoft Win32 Application Programming Interface (API) have been used. This choice relied mainly with the need for a solution as independent of PC hardware components as possible and to reduce the efforts in programming.

For Fourier transformations and neural networks used standard C++ code to optimize speed and memory requirements.

A large challenge was in triggering when to record data from a passing vehicle and digitize the signal. The sample can only be made during a car-pass and preferably without interference from other motorists, wind etc.

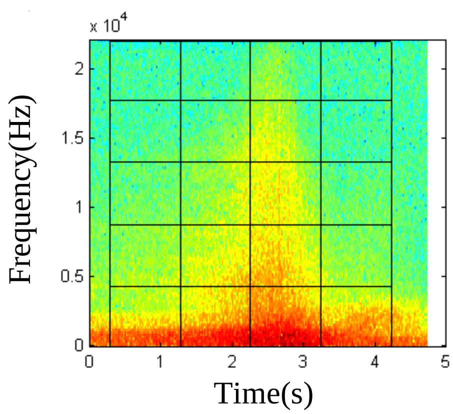

Fig 3. Typical sound frequency spectra of at passing car.

The problem of finding the position to start recording was partly solved with a circular buffer and a trigger level based on the amplitude of the incoming signal.

This involves continuous recording and then stepping backward about 2 seconds when the trigger fires.

Much work was done in order to develop a satisfactory triggering/sampling function.

As in the MARCONI module, the result from the ANN analyses are written to the MS2000 database and the sound file can also be saved or transferred.

3.4 Confidence value ensuring quality samples

As mentioned previously, there are different criteria for sampling in ARCANA and MARCONI. The acoustic system must be triggered by a passing car, and the image capture needs to be preferably sampled without any obstacles (such as a passing car) in the image.

To ensure that the classification continues with quality data, an initial process with calculation of a confidence value is performed.

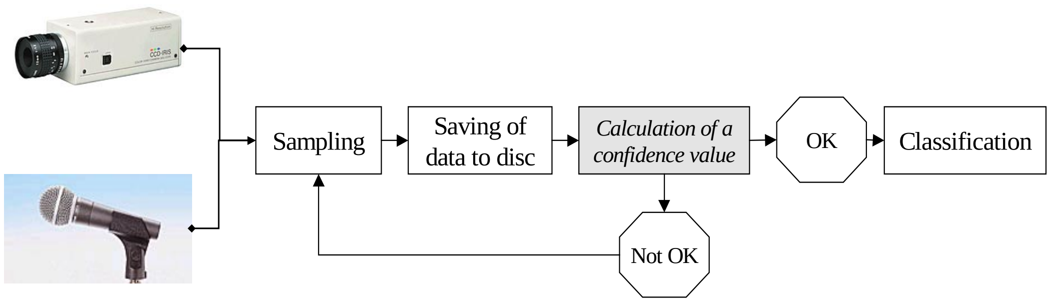

Fig. 3.3 The use of a confidence value ensures an analysis of representative data

3.5 Processing and calculation

After a representative value is saved, the system begins the classification process. This process involves extraction of certain features from the image or signal, calculations, analysis, and output to the database.

An image is digitally represented as a matrix with each pixel given a value between 0-255 in 8-bit grayscale. Different masks are applied depending on the feature which is going to be extracted. The features are normalized and classified in a specific ANN for each RCC. The final result is written to the RWIS database with one analysis result for each RCC.

In MARCONI, an automatic “MATLAB to C code generator” was first used. This caused the allocation of some 40-50 MB RAM, slow execution and extreme load on the CPU. This was caused by inefficient implementation of memory use in the code generator and by including unnecessary MATLAB functions. A huge decrease of memory requirements and processing power was achieved by rewriting the code in C++ and optimization for the application.

The process is slightly different for a sound. Here the signal is sampled and transferred to the time-frequency domain. The feature is extracted using a Short Time Fourier Transform for further analysis in the ANN.

Currently, the MARCONI software uses 8-12 MB of RAM, mostly for handling the mage matrices. The complete process time using a Pentium 200 MHz is a matter of seconds.

4 Project results

4.1 Data and data quality

This chapter goes straight on the results from the field trials – the very essence of the result from the projects. Winter 2000/2001 was the first winter where fully automatic prototypes for both MARCONI and ARCANA were operational. Both prototypes lay in the same location, Duvnäs, just north of Borlänge. In addition to being the first winter with automated prototypes extensive manual observations were made.

For the entire period from October 16, 2000 to February 11, 2001, observations were made 3 times per day at 8:00, 12:00, and 16:00. A total of 22 different road conditions were reported, see Table 4.1. The impracticality of training neural networks with so many classes is obvious dues to the low number of occurrences of many classes. For this reason, the road condition classes were reduced to the 5 classes previously used in MARCONI: dry, wet, tracks, snow, and ice. Even still the number of occurrences are not evenly distributed among these 5 classes, see Table 4.2. With only 6 occurrences of tracks, it was required to ignore this class entirely.

Original class		Reduced class	Observations	Selected MARCONI	Selected ARCANA
Dry	⇒	Dry	101	100	47
Dry/snow cloud	⇒	Dry	33	2	3
Slightly damp	⇒	Dry	22	0	0
Damp	⇒	Wet	87	1	20
Damp/salty	⇒	Wet	25	0	0
Wet	⇒	Wet	146	100	34
Wet/slush	⇒	Wet	7	0	0
Salty slush	⇒	Wet	7	4	4
Snow/salt/slush	⇒	Snow	12	8	1
Snow/slush	⇒	Snow	6	12	8
Heavy slush	⇒	Snow	6	6	2
Snow	⇒	Snow	6	23	4
Snow track	⇒	Tracks	1	0	0
Frozen	⇒	Ice	20	81	42
Frost/slippery	⇒	Ice	1	14	4
Slippery	⇒	Ice	4	1	0
Salt	⇒	Wet	4	0	1
Salt/snow cloud	⇒	Dry	3	2	0
Wet/slippery	⇒	Ice	4	0	0
Snow cloud	⇒	Snow	16	43	29
Snow/snow track	⇒	Tracks	5	3	0
Snow/salt	⇒	Snow	4	0	1

Table 4.1: Observations per road condition class distribution for training.

While road condition observations were taken 3 times daily, both images and signals were sampled much more frequently. All of the images and signals reliably close to observations were kept and the distribution among road condition classes also appears in Table 4.2. The images and signals in Table 4.2 were chosen only for their proximity to observed road condition class and not for their quality. These images and signals can be viewed as realistic in the sense that the images may contain cars on the roadbed and the signals can have captured multiple cars passing the microphone at the same time. It will be impossible to achieve 100% classification with this data, emphasizing the need for a confidence value.

For the images to be used in MARCONI, a relatively small number listed in Table 4.3 contain cars or other obstructions; between 5 and 10% of the images are unusable. The situation is somewhat worse for ARCANA. MARCONI uses a time trigger, easing the capture of a quality image.

		Images/signals	
Class	**Observations**	MARCONI	ARCANA
Dry	159	1659	542
Wet	276	1245	573
Tracks	6	-	-
Snow	50	232	107
Ice	29	222	111

Table 4.2: Number of manual observations, images, and signals per reduced road condition class

ARCANA, however, requires a trigger which detects when vehicles pass the microphone. Capturing a signal with only one car passing the microphone is not a trivial task. Fig. 4.1 shows the spectrogram of a signal from a previous ARCANA data set, illustrating a well-defined shape without any noise. Unfortunately, approximately 20% of the signals from Table 4.3 do not exhibit such a well-defined shape. Figures 4.2 and 4.3 show spectrograms of signals containing 2 vehicles and only noise respectively. The majority of the signals are well-defined but another type of noise is present. Figure 4.4 shows such an example where a grid of noise is superimposed over the vehicle’s signal form. Because the tiling used for calculating features is fairly large [1], the mean value for an entire tile should not be overly affected. The extent of this effect is not known, but perhaps a somewhat lower rate of classification has resulted.

The cause of grid lines at various time points has been pinpointed to a buffering problem during the real-time capture of the signal, see Appendix 3. The problem was detected and eliminated in March 2001, unfortunately too late to affect the results presented here. However, the cause of grid lines at various frequencies is still unknown. Since signals from precious data sets have not had the same problem, and essentially all signals in this data do exhibit the problem, the most plausible cause lies somewhere in the capture process. This problem needs to be investigated further.

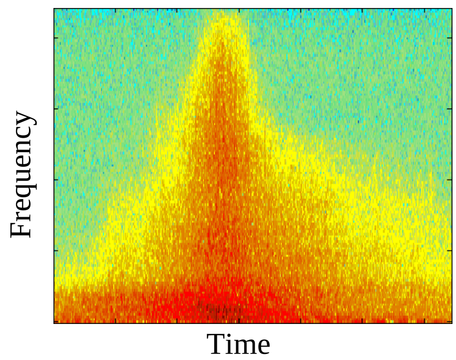

Figure 4.1: Example ideal signal

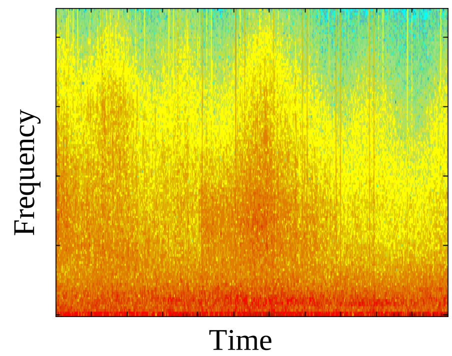

Figure 4.2: Signal with 2 vehicles

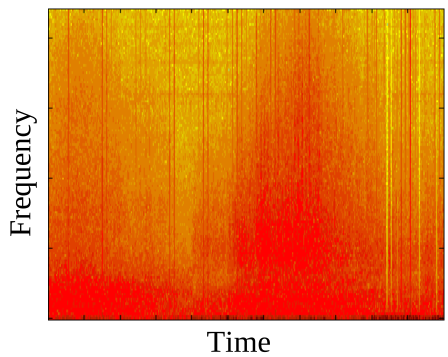

Figure 4.3: Signal with only noise

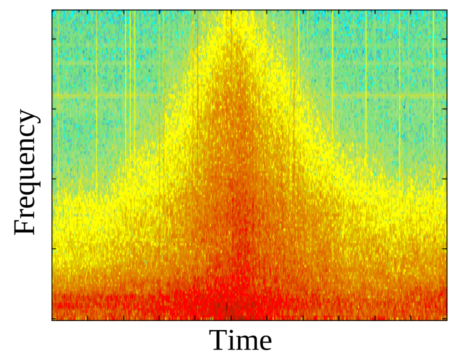

Figure 4.4: Good signal with noise at discrete times and frequencies

When examining results later in the report, one should keep in mind that up to 10% of MARCONI images and 20% of ARCANA signals are not expected classify correctly. Equally important is to insure that the poor quality images and signals do not appear in training or test sets, thus skewing the network's ability to recognize high quality images and signals. As a result, all the images and signals in Table 1 were not used to train networks. Instead, 100 images and 50 signals from each class were manually selected, as shown in the last 2 columns in Table 4.1.

These were chosen as representative images and signals of their respective road condition classes. Figure 4.5 shows typically how the road appears for the 4 different road classes. The manually chosen images and signals were then used to train the networks.

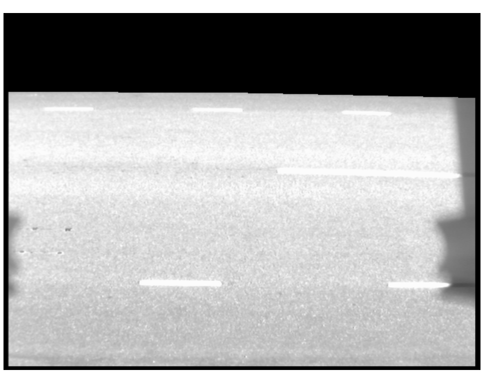
Figure 4.5a: Typical dry road

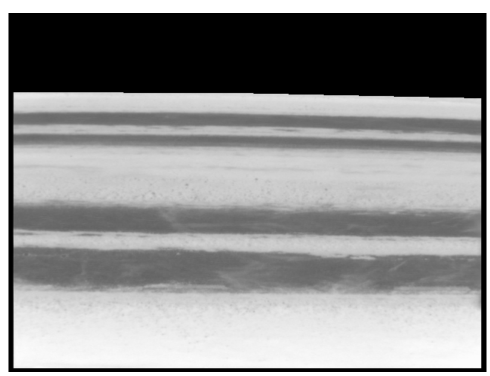
Figure 4.5c: Typical snowy road

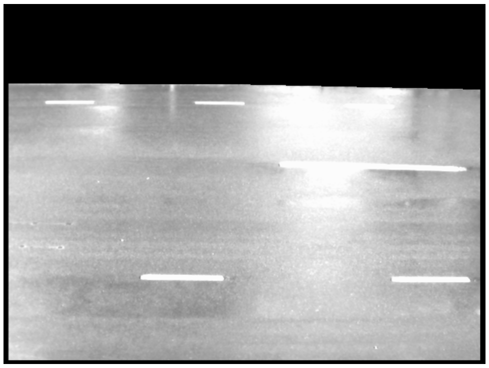

Figure 4.5b: Typical wet road

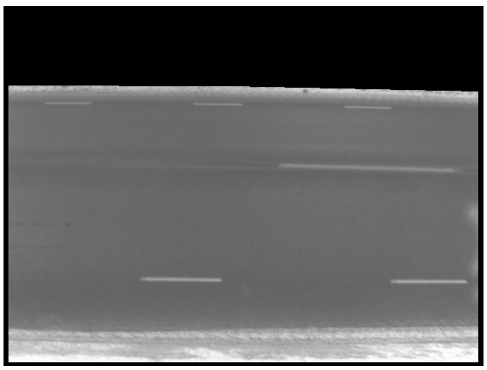

Figure 4.5d: Typical icy road

4.2 Project results - Classification using previously trained networks

During the previous 1999/2000 winter, data was collected and networks trained for both MARCONI and ARCANA. Classification networks trained with the results from the previous winter then coded into the prototypes so that classification was completed continuously in real-time throughout the winter. Results in this section reflect these real-time classifications.

4.2.1 MARCONI

For MARCONI, the same station was used with nearly identical conditions for both winters 1999/2000 and 2000/2001. This allows for a good comparison from year to year. Due to limitations in the previous data set [2], networks were trained only to recognize dry, wet, and snow conditions. Table 4.3 contains the performance of networks trained with data from the 1999/2000 winter. Performance in the validation set of the old data appears as a reference.

The error matrix in Table 4.3 shows not only what percent of images in each class are correctly classified (those figures in bold), but also the distribution among the other classes for the incorrectly classified images. For example, of the 58% of dry images incorrectly classified, nearly all classified as snow. Notice that since no confidence threshold is applied 100% of all images are retained for classification. While performance with the new data is not particularly consistent with previous performance, application of a confidence threshold filters out poor images and results in more consistent performance in Table 4.4. The largest discrepancy in Table 4.4 is that so few snowy images, only 8%, are retained after the threshold. This is most likely due to the fact that the previous network was trained only with slushy images whereas a significant portion of the new data set includes snow and snow cloud images.

Table 4.3: Error matrix for new data set using previously trained MARCONI network without confidence threshold

		Network performance				Previous performance	
		Dry	Wet	Snow	Retained	Correct	Retained
Manual observation	Dry	**54%**	4%	42%	100%	59%	100%
	Wet	23%	**46%**	31%	100%	85%	100%
	Snow	28%	3%	**68%**	100%	59%	100%

Table 4.4: Error matrix for new data set using previously trained MARCONI network with 0.1 confidence threshold

		Network performance				Previous performance	
		Dry	Wet	Snow	Retained	Correct	Retained
Manual observation	Dry	**85%**	7%	9%	36%	74%	38%
	Wet	20%	**77%**	3%	38%	100%	71%
	Snow	42%	11%	**47%**	8%	63%	32%

4.2.2 ARCANA

For ARCANA, the previous data set was recorded in Kiruna rather than Borlänge and with a different microphone. Despite such different conditions, performance of the old networks with the new data set can be of interest in order to determine if networks trained in one location can be used in another. The error matrix for classification of the new data set with the previously trained networks appears in Table 4.5.

Unfortunately, a breakdown by class of performance in the previous data set is not available and thus only weighted mean values for all classes appear as a reference. Of interest is that essentially no signals classify as snow. The snow signals from the previous data set were hard packed snow covered roads, a condition not experienced during the 2000/2001 winter season. As hard snow packed road conditions severely damp the resulting signal, it is not surprising that no signals in the new data set liken those from the previous data set. Results, see Table 4.6, are essentially the same after applying a confidence threshold.

Table 4.5: Error matrix for new data set using previously trained ARCANA network without confidence threshold

		Network Performance				Retained
		Dry	Wet	Snow	Ice	
Manual observation	Dry	**54%**	23%	0%	24%	100%
	Wet	42%	**56%**	0%	2%	100%
	Snow	26%	17%	**0%**	57%	100%
	Ice	10%	6%	0%	**85%**	100%
	Mean	52%				100%

Previous performance	
Correct	Retained
88%	100%

Table 4.6: Error matrix for new data set using previously trained ARCANA network with 0.1 confidence threshold

		Network Performance				Retained
		Dry	Wet	Snow	Ice	
Manual observation	Dry	**57%**	24%	0%	18%	20%
	Wet	38%	**62%**	0%	0%	17%
	Snow	31%	0%	**0%**	69%	15%
	Ice	5%	5%	0%	**90%**	17%
	Mean	58%				18%

Previous performance	
Correct	Retained
94%	62%

4.3 Network training

The 100 images and 50 signals in each class from Table 4.1 were split into training, test, and validation sets. The training scheme and network structure is the same as in previous MARCONI/ARCANA training [1].

4.3.1 MARCONI

The MARCONI networks were trained using 5 hidden nodes and hyperbolic tangent sigmoid transfer functions for all layers. The features used are the 14 grayscale features used previously [2]. Classification in the validation set, Table 7, is over 90% for all road classes. By applying a confidence threshold of 0, Table 4.8, classification is perfect for all classes except 90% correct for dry. Also positive is that very few examples were discarded in order to achieve such high performance.

Table 4.7: MARCONI performance in the validation set without confidence threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**92%**	1%	1%	6%		100%
	Wet	0%	**100%**	0%	0%		100%
	Snow	1%	0%	**98%**	1%		100%
	Ice	0%	0%	0%	**100%**		100%

Table 4.8: MARCONI performance in the validation set with 0 confidence threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**90%**	2%	1%	7%		76%
	Wet	0%	**100%**	0%	0%		100%
	Snow	0%	0%	**100%**	0%		97%
	Ice	0%	0%	0%	**100%**		100%

4.3.2 ARCANA

The ARCANA networks were trained using 5 hidden nodes and hyperbolic tangent sigmoid transfer functions for all layers. A total of 36 features were calculated using 6 tiles along both the time and frequency axes according to previous feature extraction methods [1].

Classification in the validation set, see Table 4.9, is extremely poor. Results using a confidence threshold rise somewhat, see Table 4.10, except for snow which is misclassified every time. Since the majority of signals used in training, see Table 1, are not truly snow-covered roads, it is likely that only an acoustic signal is not sufficient to determine for example snow cloud road conditions since they would sound essentially identical to dry conditions. However, even performance in the other classes is significantly lower than previous ARCANA trials.

Table 4.9: ARCANA performance in the validation set with 0 confidence threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**45%**	6%	16%	33%		100%
	Wet	12%	**72%**	7%	9%		100%
	Snow	21%	7%	**37%**	36%		100%
	Ice	18%	6%	23%	**53%**		100%

Table 10: ARCANA performance in the validation set with 0 confidence threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**68%**	0%	0%	32%		26%
	Wet	6%	**92%**	2%	0%		27%
	Snow	43%	21%	**0%**	36%		13%
	Ice	4%	13%	4%	**79%**		64%

4.4 Prototype performance during entire winter season

Once networks were trained using good quality images and signals, data from the entire winter season could be examined. Performance in the validation set is essentially a best-case scenario since all the images and signals are of high quality. Of interest is to see how well performance is for all of the data collected during the entire winter season. When examining results without a confidence threshold, keep in mind that ≈10% of MARCONI images and ≈20% of ARCANA signals are not expected to classify correctly.

4.4.1 MARCONI

As expected, results for all images during the winter season are significantly lower than performance in the validation set. However, performance, see Table 4.11, is still fairly good even without a confidence value. The results with a confidence threshold in Table 4.12 are good except for dry conditions. A likely cause for dry to perform worse than the other classes is that essentially only dry road conditions have the possibility of experiencing shadows on the road. Performance should increase with a sufficiently large training set including many shadowy conditions.

Table 4.11: Classification results for MARCONI during the entire winter season using newly trained networks and without confidence value threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**48%**	8%	13%	31%		100%
	Wet	23%	**46%**	6%	25%		100%
	Snow	7%	0%	**74%**	19%		100%
	Ice	16%	1%	2%	**81%**		100%

Table 4.12: Classification results for MARCONI during the entire winter season using newly trained networks and with 0.2 confidence value threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**57%**	9%	3%	32%		26%
	Wet	6%	**85%**	0%	9%		32%
	Snow	1%	0%	**81%**	18%		50%
	Ice	1%	0%	0%	**99%**		56%

4.4.2 ARCANA

Again as expected, results for the entire winter, Table 4.13, are worse than performance in the validation set. When applying a confidence value threshold, Table 14, performance for both wet and ice are very good. On the other hand, dry and snow classes are unacceptable. Many of the dry and snowy road conditions misclassify as wet. Likely, the borderline classes such as slightly damp (⇒ dry), snow cloud (⇒ snow), snow/slush (⇒ snow) are difficult to classify.

Table 4.13: Classification results for ARCANA during the entire winter season using newly trained networks and without confidence value threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**23%**	25%	18%	34%		100%
	Wet	10%	**54%**	18%	18%		100%
	Snow	14%	17%	**26%**	43%		100%
	Ice	21%	3%	11%	**66%**		100%

Table 4.14: Classification results for ARCANA during the entire winter season using newly trained networks and with 0 confidence value threshold

		Network performance					
		Dry	Wet	Snow	Ice		Retained
Manual observation	Dry	**6%**	63%	0%	31%		15%
	Wet	1%	**98%**	0%	1%		36%
	Snow	0%	30%	**0%**	70%		7%
	Ice	0%	3%	0%	**97%**		17%

4.4.3 Hybrid MARCONI/ARCANA

While performance for MARCONI and ARCANA are relatively good, an obvious way to further increase the performance is to integrate the MARCONI and ARCANA prototypes. By using the features from both sensors, performance can be increased.

For each of the ARCANA signals, an image matching the same time was taken from the database. In this way, networks could be trained using both MARCONI and ARCANA data. Results in Table 4.15, calculated for the entire winter season with a confidence threshold of 0, show that classification is acceptable for all classes except dry. The dry class was the weakest link in both MARCONI and ARCANA and continues to be a problem in the hybrid system.

Continuing the idea of combining several sensors to improve the classification, air temperature was included as an additional feature. Results in Table 4.16 are improved for dry road, but still not acceptable. Wet road conditions are by far the most commonly misclassified, likely stemming from the borderline damp road conditions. By including precipitation and humidity data as features (data which is readily available at RWIS stations), much of this uncertainty should disappear.

Table 4.15: Performance for the entire winter season for hybrid MARCONI/ARCANA system with confidence value threshold of 0

		Network performance				
		Dry	Wet	Snow	Ice	Retained
Manual observation	Dry	**4%**	63%	8%	24%	13%
	Wet	0%	**99%**	0%	0%	34%
	Snow	3%	5%	**92%**	0%	29%
	Ice	0%	0%	7%	**93%**	32%

Table 4.16: Performance with hybrid MARCONI/ARCANA system and temperature data with confidence value threshold of 0

		Network performance				
		Dry	Wet	Snow	Ice	Retained
Manual observation	Dry	**30%**	46%	4%	20%	15%
	Wet	0%	**99%**	0%	0%	36%
	Snow	0%	3%	**97%**	0%	28%
	Ice	2%	2%	8%	**88%**	36%

4.5 Confidence value during operation

Figures 4.6 through 4.8 below show how many signals were accepted for each day during the entire winter season. Additionally illustrated is how many points from the data set were collected for each given day. The MARCONI system has been operational for the longest period, approximately 120 days while ARCANA has been online for about 90 days. Holes in the plots are due to the fact that no data was available for that day.

As confidence value is sensitive to the number of examples in the training and test sets, the results for MARCONI are the closest to how an operational system would behave. Figure 4.6 shows that distribution of days with a low percentage of accepted images is essentially random. Had the accepted signals all been clustered during a few days, the system would be ineffective during certain periods throughout the winter. This is, however, not the case, thus making the system viable throughout the entire winter season.

RWIS data is compiled for every half hour and since the system takes less than 10 seconds to process an image, there are 180 chances every half hour to obtain an acceptable image. Even with a 5% accepted rate, there would still be approximately 9 images with high enough confidence in every half hour period. ARCANA has an additional problem that the system only operates when cars pass the station. For a road with traffic flow of 5000 cars per day, approximately 100 cars would pass the station every half hour leading to 5 accepted signals during every half hour period.

Accepted results for both ARCANA and the hybrid system are lower than MARCONI due to the poorer classification performance which is a direct symptom of the fact that half as many, 50 instead of 100, examples from each class were used in training. One can clearly the effect of a low number of examples in the fact that for the hybrid system, all days with lower than 15% accepted are based on days with fewer than 5 samples in the data set.

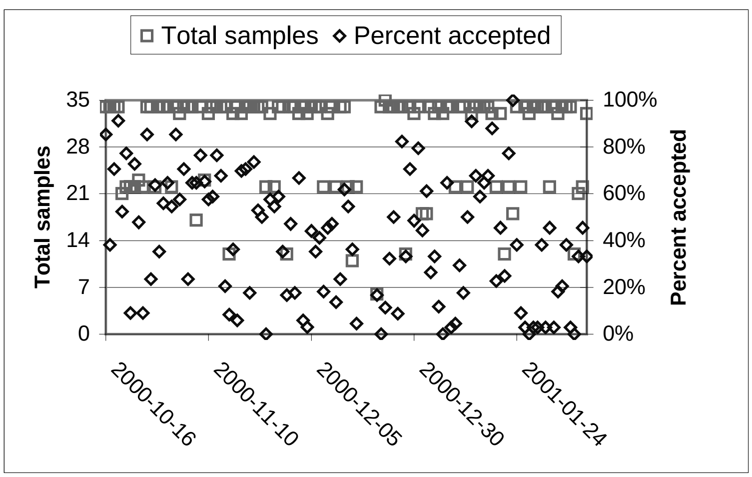

Figure 4.6: Percentage of MARCONI images per day with confidence value higher than 0.2

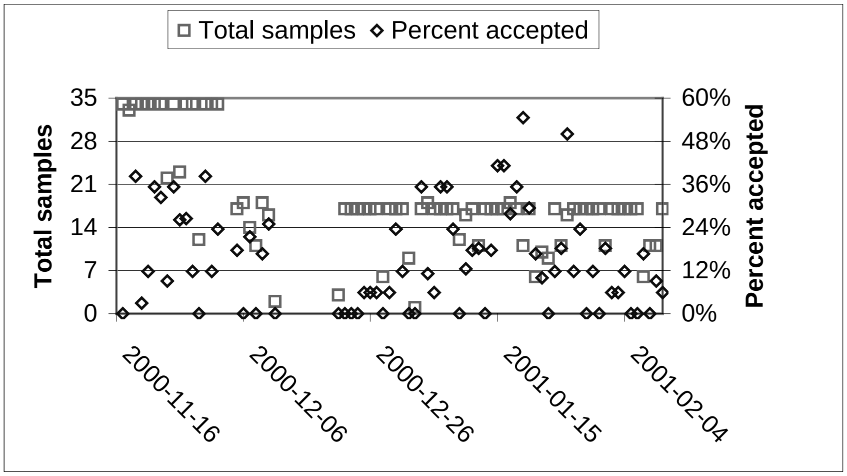

Figure 4.7: Percentage of ARCANA signals per day with confidence value higher than 0

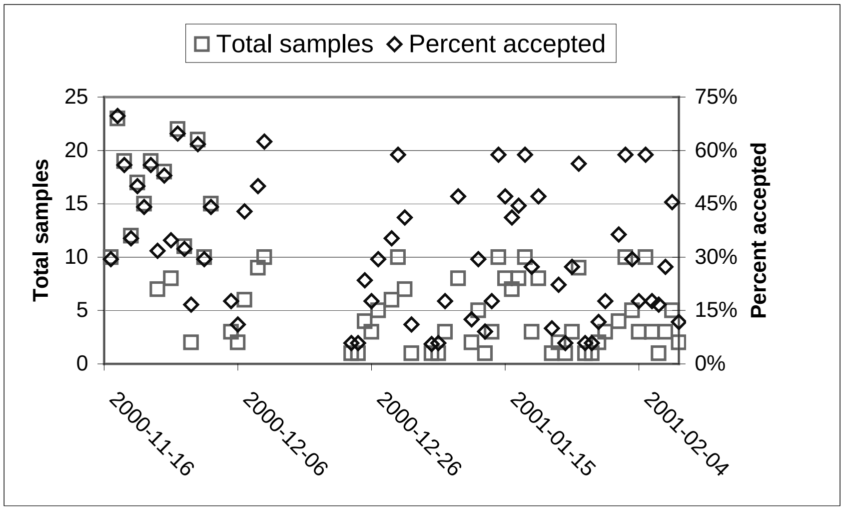

Figure 4.8: Percentage of MARCONI/ARCANA/temperature hybrid data points per day with confidence value higher than 0

4.6 Marconi operating hours

A major drawback to MARCONI is that it is only effective during daylight hours. Table 17 approximates by month the hours that MARCONI can be operational in its current form.

It is unclear whether the system could be extended to include nighttime operation, with infrared lighting for instance.

Month	Operational time span
October	07:00 – 17:00
November	08:00 – 16:00
December	09:00 – 15:00
January	09:00 – 15:00
February	08:00 – 16:00
March	07:00 – 17:00

Table 17: Times per month when MARCONI is effective

5 References

[1] K. McFall, “Artificial Neural Network Technologies Applied to Road Condition Classification Using Acoustic Signals”, Internal project report, 1999.

[2] K. McFall, “Continuing Work on MARCONI: Prototype Testing and Investigation of Detecting Road Condition Trends”, Internal project report, 2000.

[3] Teknisk rapport, L Sahlin, L Lindstöm

[4] A. Svärdström, “Klassificering av Väglag med Hjälp av ett Neuralt Nät”, Uppsala University Institute of Technology publication, ISSN 0346-8887, June 1993.

[5] T. Nittola, Datainsamlingsproblem vid station L60, Internal report 2001.