SIXTH FRAMEWORK PROGRAMME
PRIORITY IST
FET - Open Domain

Contract for :

SPECIFIC TARGETED RESEARCH PROJECT

Annexe I- “Description of work”

Acronym: FLUID

Project full title: FLUid Image analysis and Description

Proposal/ Contract number: FP6-513663

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Contents

1 Project summary

Proposal full title: FLUid Image analysis and Description

Proposal acronym: FLUID

Proposal abstract:

This interdisciplinary project, that we have entitled FLUID, aims at studying and developing new methods for the estimation, the analysis and the description of complex fluid flows from image sequences. We propose to devise novel image processing and computer vision methods by using sound methodological frameworks incorporating suitable physical models accounting for the observed phenomena. This domain of research encompasses a wide range of difficult issues and thus will have a significant impact on several scientific and application domains including meteorology, oceanography, and flow visualization in applied fluid mechanics. The first objective of our proposal consists in studying novel and efficient methods to estimate and analyse fluid motions from image sequences. The second objective is to guarantee the applicability of the developed techniques to a large range of fluid visualization applications. To that end, two specific areas will be considered: meteorological applications and experimental fluid mechanics for industrial evaluation and control. From the application point of view the project will particularly focus on 2D and 3D wind field estimation, and on 2D and 3D particle image velocimetry. A reliable description of the fluid flow velocity will allow us to study techniques for the tracking of turbulent structures in the flows. Such problem is very important in meteorology to monitor or to predict automatically displacements of tornadoes and vortices.

2 Project objectives

2.1 Motivations

Complex physical fluid flow phenomena in physical sciences and industrial production.
Complex fluid flow phenomena abound both in nature and technology. In environmental sciences such as oceanography, meteorology and climatology, complex flows are caused by the transport of energy and matter within the atmosphere, in oceans and ashore. In life sciences, organisms comprise complex flows at various scales, ranging from the macroscopic level (e.g. blood flow or deformation of brain tissues) to dynamic structures at the cellular level (e.g. flow through membranes). In industrial production, the engineering of flows is of utmost importance for various processes related to aero– and fluid dynamics, combustion or chemistry.
A common feature of these flow phenomena is *the lack of a complete physical understanding of the underlying dynamics* which prevents their accurate prediction and control. Figure 1 illustrates these facts by fluid flows arising in industrial applications and in the atmosphere.

Figure 1: Complex flows from industry and meteorology

Imaging sensors for fluid flow measurements.
Due to the rapid progress of semiconductor technology, a broad range of industrial CCD and CMOS imaging sensors are nowadays available taking images at every desired resolution and speed. A primary advantage of these devices is that they provide spatio-temporal data in a fast, tireless, reproduceable and contact–free way. Satellite images provide us with multispectral image data from dynamic processes in the atmosphere. Microscopy and tomography is the key to diagnosis and analysis in life sciences. Cameras coupled with laser light are one of the principal techniques used for measurement and analysis of fluid flows in aero/hydro-dynamics, for combustion studies, and in mixing processes within chemical industries.
A decisive advantage of imaging sensors over alternative physical sensors in the context of this project is that they continuously provide accurate measurements at a high spatial resolution *which hardly can be obtained with sufficient consistency by current physical models and their numerical evaluation.* As a consequence, in order to make progress with respect to the understanding and control of complex fluid flow phenomena, image processing is often the only choice.

Objectives of the project.
The **first** objective of the project is:

- Development of *novel and dedicated techniques for the processing and evaluation of image sequences* from complex fluid phenomena.

The **second** objective is to guarantee the applicability of the developed techniques to the whole range of applications fields described above. To this end, two specific but different application areas from industry and geoscience are considered:

- Understanding and evaluation of complex fluid flow phenomena for industrial air flow control, and
- Understanding and evaluation of complex fluid flow phenomena in the atmosphere.

The consortium combines researchers and expertise from *image processing, computer vision, computer science, mathematics, fluid mechanics, turbulence, meteorology, imaging sensor industry,* and *food industry* in order to reach these objectives. The consortium includes five academic groups and one industrial company specialized in the development of experimental visualization systems for fluid flows. All the research groups, which cover the three main scientific domains (Computer vision, Meteorology and Fluid mechanics) listed above are experienced and internationally known for their work.

2.2 State of the art — deficiencies of current techniques

Techniques for image sequence analysis and computer vision.
Research concerning the mathematical and algorithmic foundations of image analysis has made substantial progress during the last decade. Nonlinear multi-scale image analysis [3], efficient image signal decompositions [12, 7], PDE-based image processing techniques [5], stochastic modeling or probabilistic tracking approaches, [9, 10, 17, 4], and variational approaches for feature extraction and segmentation [14] nowadays are state of the art.
Concerning the analysis of dynamic structures in image sequences, a wide range of approaches are available for estimating dense velocity vector fields. These approaches, however, are mainly driven by computer vision research where mostly the dynamics of *rigid objects* in the scene are considered. Consequently, the underlying mathematical representations, the assumptions involved, and the physical constraints taken into account have to be completely revised in order to focus directly on the objective of this project: the analysis of *highly non–rigid fluid flows* using image sequences. To this end, combined efforts from the fields of image processing, computer science, mathematics, physical sciences (more precisely meteorology and fluid mechanics) and industry are necessary.

Visualization in experimental fluid mechanics Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) are undoubtedly the most successful techniques based on image analysis for the measurement of velocity fields. With these methods, the fluid is seeded with particles, or markers, that can be imaged and tracked using correlation type methods [1, 13]. The increasing use of PIV in research and industrial laboratories has allowed the development of specific lasers, cameras and softwares dedicated to velocity measurement. Micro-inspection systems and high-speed devices have recently enlarged the application field to micro-fluidics (micro-structures, MEMS, biomedical flows) and to the temporal analysis of turbulent flows. One of the major limitations of PIV and PTV relies on the incomplete ability of the algorithms to retrieve the information contained in the image sequences. The use of correlation methods inside pre-defined interrogation windows yields relatively sparse displacement fields and strongly limits the range of spatial scales over which the flow structures can be analysed. This hinders the capture of complex fluid flow phenomena like turbulent structures which rise at a wide range of scales simultaneously. There is clearly a need to design image processing techniques able to take full advantage of the growing spatial and temporal resolution of the imaging sensors dedicated to fluid flow measurement.

Image sequence analysis in meteorology.

In oceanography and meteorology the methods for providing oceanic and atmospheric flows as well as trajectories of corresponding flow structures rely on the analysis of satellite images from different spectral channels (visible, infra-red, water-vapor). The corresponding methods track points exhibiting sufficient characteristic local image structure over time based on various consistency assumptions (geometric and/or photometric) [16]. This amounts to correlation–type techniques similar to PIV described above. As a consequence, these methods suffer from the same deficiencies described above.

The availability of new generation satellites, with new channels and better resolution in space and time makes necessary to re-examine the tracking methods. Furthermore, there is a renewed need to study the trajectories of air particles, linked to the validation of their representation in meteorological models.

2.3 Tasks and issues to be addressed

The study image sequences depicting fluid flows within the FLUID project addresses a large set of problems. The issues involved range from low-level vision to physical modeling and validation. On one hand, adequate novel image analysis techniques are needed in order to reliably extract features of fluid structures. On the other hand, taking into account general laws governing the evolution of the flows is mandatory because the highly deformable “objects” of interest can only partially be observed due to the projection of 3D-space section onto an image plane and to unknown boundary conditions. The interplay between 2D image measurements and complex dynamical systems in three dimensions along with corresponding physical models constitutes the core problem of the FLUID project. Its solution requires the cooperation of scientists from the fields of image analysis, computer vision, computer science, mathematics, and fluid mechanics.

As for the evaluation of such dedicated methods, we have to face another serious problem. In fact, it seems that the only admissible way to evaluate such methods is to statistically verify *a posteriori* that known physical invariants of the flow are preserved and to check if some *a priori* known events are well measured or predicted. To this end, data provided by controlled experimental processes and/or by numerical simulations have to be provided. The results of different methods can then be statistically compared in order to assess their reliability and accuracy. Such a statistical comparizon is done on the basis of a measurement of some physical parameter obtained from a large sample of results provided by the methods of interest on controled flows for which the actual value of this parameter is known.

For turbulent flows such as the atmospheric flow the evaluation can only be performed qualitatively by experts. In that case, some phenomenon or some state variable (pressure, temperature, wind velocity, ...) observed indirectly or directly through various probes can be checked to be well retrieved or tracked by the method studied.

We believe that the association of qualitative evaluation on turbulent atmospheric flows coupled with a quantitative statistical evaluation on controled experimental flows with known theoretical characteristics will allow us to assess both the accuracy and the generic form of the methods we aim to develop.

Such an evaluation process requires concerted experimental simulation studies and a tight cooperation between fluid mechanics experts and image analysis researchers. A “closed loop” process between these two parties should in addition enable an improvement of the different methods under development by precise feed-back with respect to both their qualities and deficiencies.

In summary, the following tasks and issues have to be addressed within the FLUID project:

- Creation of an image database with controlled 2D/3D experimental and numerical flow fields.
- Design of tractable applied physical models.
- Computation of 2D fluid flow fields from image sequences
- Computation of features related to 3D flow fields from 2D image sequences
- Extraction and tracking of specific fluid flow structures
- Validation of the developed techniques for 2D/3D flow field computation
- Comparison of the novel methods with current state-of-the-art techniques

At a finer scale, the following specific topics have to be addressed by the FLUID consortium according to the expertise of the partners involved:

- Efficient multiscale filter banks for pre-processing
- Vector field representations (div/curl decomposition)
- Multiscale vector field estimation
- Multi-layer representation and coupling
- Stereoscopic 3D motion estimation
- Structure representation (vector field) and motion segmentation
- Structure tracking, non-linear filtering
- Numerical aspects (domain decomposition/multigrid interactions)
- Design and integration of physical models and constraints
- Characterization of turbulent structures
- Synthetic benchmark tests via Direct Numerical Simulation of various 2D/3D flows
- Real benchmark test by experimental approaches of various controlled 2D/3D flows
- Statistical analysis of the results and their physical interpretation

References

[1] R. J. Adrian. Particle-imaging techniques for experimental fluid mechanics. *Ann Rev Fluid Mech*, 23:261–304, 1991.

[2] R. J. Adrian. Bibliography of particle velocimetry using imaging methods: 1917-1995. UILU-ENG-96-6004 817, Theoretical amd Applied Mechanics - University of Illinois at Urbana-Champaign, 1996.

[3] L. Alvarez, F. Guichard, P.L. Lions, and J.M. Morel. Axioms and fundamental equations of image processing. *Arch. Rat. Mech. Anal.*, 123:199–257, 1993.

[4] A. Blake and M. Isard. *Active Contours*. Springer, 1998.

[5] V. Caselles, J.M. Morel, G. Sapiro, and A. Tannenbaum, editors. *IEEE Trans. on Image Proc.: Special Issue on Partial Differential Equations and Geometry–Driven Diffusion in Image Processing*, volume 7/3, 1998.

[6] A.J. Chorin and J.E. Marsden. *A Mathematical Introduction to Fluid Dynamics*. Texts in Applied Mathematics, Vol. 4. Springer-Verlag, 1993.

[7] I. Daubechies and W. Sweldens. Factoring wavelet transforms into lifting steps. *J. Fourier Anal. Appl.*, 4(3):245–267, 1998.

[8] R.M. Ford, R. Strickland and B. Thomas. Image models for 2D flow visualization and compression. ,*Graph. Mod. Image Proc.* 56(1):75-93, 1994.

[9] S. Geman and D. Geman. Stochastic relaxation, gibbs distributions, and the bayesian restoration of images. *IEEE Trans. Patt. Anal. Mach. Intell.*, 6(6):721–741, 1984.

[10] D. Geman. Random fields and inverse problems in imaging. In P.L. Hennequin, editor, *École d'Été de Probabilités de Saint-Flour XVIII – 1988*, volume 1427 of *Lect. Notes in Math.*, pages 113–193, Berlin, 1990. Springer Verlag.

[11] M. Lefébure and L.D. Cohen. Image registration, optical flow and local rigidity. *J. of Math. Imag. Vision*, 14(2):131–147, 2001.

[12] S. Mallat. *A Wavelet Tour of Signal Processing*. Academic Press, 1998.

[13] S.P. McKenna and W.R. McGillis. *Performance of digital image velocimetry processing techniques* Experiments in fluids, 2002, 32, 106–115

[14] J.-M. Morel and S. Solimini. *Variational Methods in Image Segmentation*. Birkhäuser, Boston, 1995.

[15] A. Quarteroni and A. Valli. *Domain Decomposition Methods for Partial Differential E-quations*. Oxford Univ. Press, 1999.

[16] J. Schmetz, K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gaertner, A. Koch and L. Van de Berg. Operational cloud-motion winds from Meteosat imagery. Journ. of Appl. Meteor., Vol. 32 1206–1225, 1993.

[17] S.C. Zhu and D. Mumford. Prior learning and gibbs reaction–diffusion. *IEEE Trans. Patt. Anal. Mach. Intell.*, 19(11):1236–1250, 1997.

3 Participants list

List of Participants

Partic. Role	Partic. no.	Participant name	Participant short name	Country	Date enter project	Date exit project
CO	1	INRIA	VISTA	France	1	36
CR	2	University of Mannheim	CVGPR	Germany	1	36
CR	3	University of Las Palmas	AMI	Spain	1	36
CR	4	CEMAGREF	AEROBIO	France	1	36
CR	5	LaVision	LaVison	Germany	1	36
CR	6	CNRS	LMD	France	1	36

4 Relevance to the objective of FET Open

The objective of the **FLUID** project is to design new methods for the processing and the physical analysis of image sequences of complex (natural or experimental) fluid flows, in particular involving the computation of dense and accurate 2D and 3D velocity fields (and associated physical quantities such as vorticity fields), the detection, tracking and characterization of (usually non stationary) dynamic fluid–flow structures.
The study of fluid flows from image sequences is undoubtly of major interest in numerous applicative domains of two key areas for the EU community and its economic development: *environmental sciences* (meteorology, oceanography, climatology) and *the engineering of flows* in industrial production (study of microfluidic technologies, aero/hydro-nautics, flow control, ...).
Continuously growing interest and investment are put in these application areas which concern both the community in general, everybody in his/her daylife, economical and industrial activities. The foreseen economic development induced by handling these issues will however not occur in the EU at a large scale if the corresponding advanced technology is not designed and available inside the EU. In this respect, the **FLUID** project will bring significant contributions.

To achieve its goal a strong point of the **FLUID** project relies in its interdisciplinary nature bringing together computer vision researchers, meteorologists and fluid mechanics experts. We believe that this interdisciplanarity is essential and will finally garantee to give birth to *generic methods incorporating naturally sounds physical models into well founded analysis methods*. Such a scientific reasoning is essential to design accurate and generic fluid motion analysis from image sequences.
The **FLUID** scientific and technogical goals are ambitious. They are obviously not straigthforward as the **FLUID** project proposes to study complex dynamical evolution models within analysis methods which may themself lead to tricky numerical problems. Due to the potential impacts of such a study we sincerely believe that this project is worth deepening.
The interdisciplanarity scientific difficulties of such a project together with the various skills needed to undertake it, makes it almost unfeasible to realize without a tight cooperation between different European expert groups and a long time research funding.

5 Potential impact

5.1 Reinforcing European competitiveness

Recently, motion estimation and analysis proposed in the computer vision community has come to maturity. These techniques which allow to estimate almost in real time dense motion fields are nevertheless only adapted to rigid body assumption and textured noiseless video sequences. On the other hand, techniques used to estimate velocities of fluid flows from images are based on correlation techniques which are non dense by nature and prone to errors. High improvements can be expected in devising motion analysis methods dedicated to fluid images in which the European community has the chance to play a leading role through the FLUID project.
An investment of the European community in the FLUID project will enable to establish – for the first time – an *interdisciplinary* research consortium concerned with the analysis of fluid flows from image sequences. Only few studies on the subject exist in different scientific areas, yet the required interaction between different disciplines for a deeper study and innovative solutions is missing. In addition, publications resulting from this project would increase the

awareness of various researchers with respect to the interest and impact of the investigated issues, thus multiplying the investment value many times.
The exploitation of the results of the FLUID project should also allow the European industry to improve its position in the field of experimental fluid mechanics with respect to US companies.

5.2 Contribution to policy developments

The project will actively contribute to scientific policy developments in several ways.

5.2.1 Contribution to strategic application domains

By devising new approaches for the analysis of fluid-image sequences, the **FLUID** project will contribute to several application domains of great interest for the community. The scientific domains involved include environmental sciences (meteorology, climatology, oceanography), experimental visualization in fluid mechanics and biomedical imagery. Important applications related to these domains and of major economic and societal impact need to rely on efficient software solutions to extract, characterize and track dynamic entities over time. Such an analysis is an unavoidable prerequisite that must be reliable and accurate enough to facilitate any further process or analysis. We give here under a non exaustive list a list of applications of crucial interest for *environment* and *industry*.
As for environment issues the analysis of satellite image sequences allows to study the way the atmosphere or the ocean evolves and can provide tools for:

- the reconstruction of the wind fields;
- the extraction, characterization, and tracking of important dynamical entities such as throughs of low pressure, tornadoes or vortices;
- the detection of sudden and critical meteorological situations (e.g., convective systems);
- the detection and tracking of icebergs, fish eggs, larvae, or polluting agents in oceans;

All these issues strongly impact meteorological now/fore-casting, and atmospheric or oceanic surveillance and study.

In the domain of **experimental fluid mechanics**, the visualisation of fluid flows plays a major role for turbulence analysis. One of the major goals pursued at the moment by more and more scientists and engineers consists in studying the ability to manipulate a flow to induce a desired change. This is of immense technological importance in order to control energetic output, mixing in shear flows and physical effects of strain and stresses. This is for instance of particular interest in:

- military applications, for example to limit infra-red signatures;
- aeronautics and transportation, to control drag and lift effects of turbulence and boundary layer behaviour;
- industrial applications, for example to preserve manufactured products from contamination by airborne pollutants.

The methods that will be devised in the **FLUID** project can also be of potential benefit to the **bio-medical** and **bio-mechanical** domains. As a matter of fact, research and industrial developments in bio-fluid studies require accurate methodologies to visualize and analyse flows in real or artificial organs. Such visualization methods and associated measurements could be beneficial for:

- analysis of blood flows and detect pathological cases such as stenosis;
- improvement of the design of artificial organs and implants in order to limit problematic turbulences.
- development of microfluidic devices to conduct biomedical research and create clinically useful technologies.

5.2.2 Subsequent innovation in industrial technologies

The FLUID project will yield novel original methods for analyzing fluid flows from image sequences taken in different contexts. This, in turn will lead us to the development of industrial technologies exploiting imaging sensors in the context of fluid flow analysis for forecast, surveillance, inspection or control purposes. The presence of an industrial partner in the FLUID project enforces the consortium to take into account industrial needs and knowledge transfer right from the beginning.

5.3 Exploitation/further research

The methods provided by the FLUID project will be helpful for numerous research laboratories as tools to extract wind fields in meteorology or PIV maps in experimental fluid mechanics and to compute different physical values for the analysis of flows. The new developped methods should substitute for classical limited techniques based on correlation with an improvement in accuracy and an increased volume of valuable and reliable numerical information (due to the dense nature of the techniques we propose). The incorporation of physical laws in the image models will also lead to subsequent increse in robustness of these techniques. In addition, we believe that the FLUID project will constitute a first step toward studies crossing scientific domains such as Fluid mechanics, Meteorology and Computer Vision. Each of these domains should benefit from cross fertilized skills and experiences up to now limited to separated scientific communities. Computer vision partners will bring the most recent leading techniques to analyse videos and images. In the other hand, meteorologists and fluid mechanists will offer their knowledge in modelization of fluid phenomena to specialize generic computer vision techniques. Tis corpus of novel methods should in turn give raise to new developpments in the different concerned application domains. It will supply the appropriate support to exploit more efficiently image data for analysis or visualization purposes.

5.4 Communication strategy

The project participants will involve themselves to support to organize or participate to workshops and summer schools. At these occasions, the partners will presents the methods and the results devised within the FLUID project to their scientific community (Computer Vision scientist, Meteorologist, or Fluid mechinacian)
The whole plan for disseminating knowledge is described in sections 6.2 and 6.3
Besides, the consortium will spread awareness and information about the project and its results beyond the scientific community. As a matter of fact, each of the partners participate each year to “open doors”, science fairs, and other exhibitions targeted to a non scientific public. At these occasions all the partners will promote the FLUID project. Demonstrations suited to this

audience will be presented. For instance the meteorological applications, more familiar to most people, will be highlighted.

5.5 Risk assessment and related communication strategy

This project does not raise to particular ethical questions it neither lead to particular riks regarding potential missuse of the techniques developped during this project. No communication strategy with respect to potential risk has been therefore setlled.

6 Project management and exploitation/dissemination plans

6.1 Project Management

The **Project Leader** will lead the overall management of the project, which is encapsulated in **WP6**. Apart from the kick-off meeting, a consortium meeting will be organized every six months. These six meetings will comprise scientific sessions and a management one. Every partner will have a representative in each management session which will be chaired by the Project Leader. Outside of these meetings, all the partners will be in constant communication with each other via electronic mail. A project web site will be settled. This web site will gather data, technical reports or notes produced at the different milestones of the workpackages. The site will also include different demos on methods developed during this project. These pages will be devoted to the dissemination of the different demonstration activities realized in the different workpackages. This part of the site will be completely open and accessible. A confidential part will allow the participants to exchange easily notes, data and results.

The Project Leader will appoint for the duration of the project a **Coordination Assistant** who will be responsible for the following issues : interface with the commission; collecting, distributing and maintaning a data-base of deliverables and reports; maintaning the project web pages; responding to enquieries about the project; meeting arrangements, logistics and minutes. The coordination assistant will ensure that all issues and news are communicated promptly to the whole consortium and to the commission. All partners will deliver any financial, legal or technical information to this coordination assistant. The project leader will notify all partners of the availability of deliverables once received.

At every six-month meeting (management session), the **Project Committee** comprising a representative of each partner will track the progress of project against the schedule outlines in the proposal and agree on detailed project action plan. Since the **FLUID** project addresses challenging and difficult research issues and involves a substantial inter-dependency between partners, there is the risk of slippage of the project schedule and a corresponding need for additional measures to safeguard the milestones and deliverables. The members of the Project Commitee will discuss and decide rearrangement of the working plan if necessary.

The scientific sessions will include sessions concerned with general or transversal scientific issues likely to concern all the partners, and sessions (according to each WP schedule) devoted to the task advancement of each WP. Each WP leader will be in charge of organizing the corresponding WP session. If necessary, supplementary meetings for a given WP (or a given task) could be settled in one of the WP partner sites and involving only the concerned partners. These visits will be particularly useful for tasks requiring a close collaboration between two or more partners.

The relationship between the partners and the Commission is covered by the Contract. It also covers basic rights and responsibilities of and between the participants. It is augmented by a Consortium Agreement between all partners.

Each of the participants will stay owner of the softwares and methods they developed prior to this project. The property of the softwares and methods developed in the project will be shared by the partners involved in their realization. Possible commercial exploitation will be negotiated if opportunities arise.

6.2 Plan for using and disseminating knowledge

Knowledge dissemination

The **FLUID** project consortium will devote significant effort to ensure that full advantage is taken of opportunities for disseminating its results through active participation in the scientific communities. This will include submission of articles to renown international journals, to major conferences both in image processing and computer vision such as the European Conference on Computer Vision (ECCV), the International Conference on Computer Vision (ICCV), the International Symposium on Flow Visualization (ISFV), and in specialized workshop such as the international Winds Workshop, the Eumetsat Meteorological Satellite Data Users' Conference or the International Symposium on Particle Image Velocimetry. Members of the **FLUID** project have already published in these conferences.

Furthermore, the consortium plans to organize an open interdisciplinary workshop on fluid motion analysis from images (with a call for papers) during the last year of the project. It will enable to highlight the main theoretical and applied results of the **FLUID** project, while gathering the most valuable contributions of other groups working on that domain or on related domains at an international level. It will offer a unique inter-disciplinary forum on flow visualization. The publishing of the proceedings of this workshop will also contribute to the dissemination effort.

Another route to dissemination will be through the website of the **FLUID** project, which will allow researchers to access publications arising from the work of the project, as well as giving access to concrete demonstrations of results obtained by the methods developed within the project. The applicative and industrial partners will also present demonstrations of the project results at exhibitions concerned with experimental flow vizualisation.

Economic development and exploitation.

One of the objectives of the project is to extend skill and knowledge recently developed in the computer vision community, to give new responses to the expectations of the applied fluid mechanics community and flow visualization end-users. In that community, there is a gap to fill between the qualitative visualisation analysis made by an expert, and the quantitative measurements today available that give only limited information on physical variables. The PIV technique is an attractive experimental tool which through successive improvements appears to be more and more accurate in measuring velocities and turbulence parameters. However, its basic principle requires that the user *a priori* selects a given scale at which the studied phenomena will be measured. It leads to strong limitations in the ability of the technique to provide accurate, dense and reliable information for complex flow patterns with high velocity gradient regions, and exhibiting multiscale coherent structures coexisting with a developed turbulence. Since numerical simulation is more and more able to give complete information, at different scales for various virtual flows, it is of particular interest to tackle the problem of getting equivalent informations for real flows. Therefore, the first commercial opportunity will be to improve the existing PIV systems by offering, on the same basis (estimation from a pair of laser-sheet lighted plans) measurements on the observed physical phenomena at different scales. Furthermore, it will be possible to design new materials exploiting multiple image sequences, supplying more comprehensive and accurate information than PIV does. The existence of new algorithms integrating the techniques issued from the **FLUID** project will allow an industrial company such as LaVision to produce integrated systems comprising single or multiple rapid cameras, adapted lighting systems, in coherence with these algorithms. These new developments will be of particular interest in the competition, in European, US and Japan markets, against extra-european companies. The potential market for the **FLUID** project results is very important. It concerns a broad range of industrial applications related to the environment monitoring and to industrial needs for various flows visualization.

6.3 Raising public participation and awareness

Each of the partners participate each year to "open doors", science fairs, and other exhibitions targeted to a non scientific public. At these occasions all the partners will promote the FLUID project. Demonstrations suited to this audience will be presented. For instance the meteorological applications, more familiar to most people, will be highlighted.

7 Detailed implementation plan for full duration of the project

7.1 Introduction - general description and milestones

The workplan of the **FLUID** project is divided into 6 workpackages. Each workpackage corresponds to a coherent set of tasks going from data acquisition and early processing to motion analysis and evaluation. Workpackage 6 corresponds to the management. Due to the nature of the scientific and technical tasks involved in our proposal, we have preferred to associate demonstration activities to each WP, instead of creating a WP specifically dedicated to global demonstration activities. A substantial and appropriate amount of resources will be clearly devoted to these activities, typically 25of the concerned WPs.
Each workpackages is divided in research activities, demonstration activities and management activities. For all the workpackages, the data used, the results of the methods proposed and developped in the context of that project will be publicly avalilable on a web site. This web site which will be developped and maintain by the consortium coordinator will also include all the reports and research papers relative to this project. It will be explicitly ask to each partners to
The workpackages composing the whole project are organized as follows:

Workpackage 1 : *Creation of an image sequence database with 2D/3D meteorological, experimental and numerical flow fields.* This workpackage is devoted to the acquisition and the diffusion of the different kinds of data needed by the partners to implement the proposed methods. The concerned data will be satellite meteorological images and experimental fluid flow vizualization data sequences. The latter includes images, sparse velocity fields or kinetic measurements such as *vorticity*. Some specific experimental flow sequences will also serve as a benchmark for the evaluation process.

Workpackage 2 : *Physical models for 2D and 3D fluid motion computation.* This workpackage adresses issues of 2D motion estimation from fluid-flow image sequences. This comprises tasks of *local* motion estimation through efficient filter banks and of *global* motion estimation. The last issue involves design of appropriate *priors* or studies of efficient vector field decompositions. All these tasks will be followed by taking into account tractable physical models and constraints. Furthermore, this workpackage will address the study of efficient numerical *multiscale* schemes.

Workpackage 3 : *2D fluid motion analysis.* The objective of this workpackage is to design higher level tools for fluid motion analysis. The aim is here to develop methods allowing us to detect, characterize, and track particular structures in the processed image sequence. The considered approach will mainly rely on parametric description of the velocity field. The extracted motion descriptors will also serve as basis models for the techniques developed in workpackage 4.

Workpackage 4 : *3D fluid motion estimation.* This workpackage addresses a very challenging topic: the computation of 3D motion information for fluid flows. Two different issues will be investigated: the estimation of 3D velocity of particles in a light sheet plane, and the estimation of several interacting 2D velocity fields organized as successive motion layers corresponding to different depth or altitudes. The first case is mainly relevant to experimental visualization of fluid flows whereas the second one is well suited to atmospheric 3D-like flow description from meteorological satellite image sequences.

Workpackage 5 : *Experimental evaluation and physical interpretation of the results.* This last workpackage aims at assessing the different methods developed in the **FLUID** project. The evaluation will be carried out for well-controlled flows whose theoretical behaviors are known and for which numerical invariant quantities may be recovered. The goal is two-fold: quantitative comparisons between the different methods developed and physical interpretation of the obtained results. The evaluation will also be conducted in a qualitative way for experiments with no precise available ground-truth.

Figure 2 outlines the interaction between these workpackages. In this flow chart, the colored arrows correspond to different kinds of interaction between the workpackages defined above. The blue arrows represents *input data*, whereas the yellow ones indicate *output results*. These

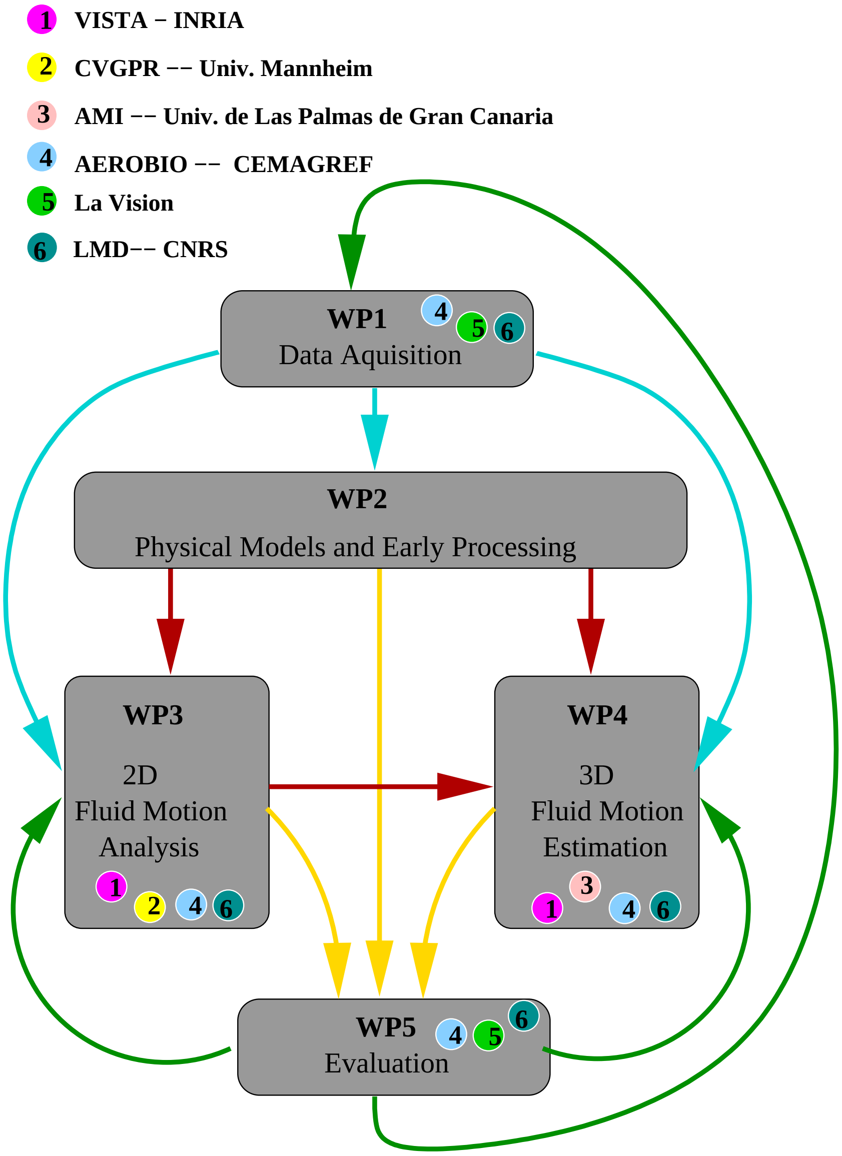


Figure 2: Sketch of the **FLUID** Workplan

top-down interactions descend from the Data acquisition workpackage to the Evaluation workpackage. The red arrows denote *models and methodological* interactions. They gather exploitation of methods, results or models. This is clearly a top-down flow from early processing to

higher level processing. The green arrows indicate feedback dependencies from the evaluation workpackage to all the others. The evaluation process also aims at diagnosing defaults in order to improve or re-direct, if needed, the developed methods.
We now describe in detail each of these workpackages, along with the *management* workpackage (**WP 6**).

WP 1: Creation of an image sequence database with controlled 2D/3D experimental and numerical flow fields

Lead Partner: 4

The objective of this workpackage is to produce complete sets of data comprising :

- meteorological satellite atmospheric image sequences
- first sets of image sequences of controlled fluid mechanics experiments (air flows in wind tunnels), produced in a classical way using laser-sheets and cameras, with a smoke or particle concentration chosen a priori in order to give reasonably detectable contrasts
- second sets of experimental image sequences produced in an adapted manner (seeding, lighting, frame size, physical data range) after feedback from tests conducted in WP 2, WP 3 and WP 4.
- synthetic image sequences coming from the results of Direct Numerical Simulations (DNS) of a shear flow (mixing layer)
- quantitative data characterising the flows corresponding to each set of experimental image sequences, among which global and local physical characteristics like velocity fields, statistics, spatial correlation as well as topological dimensions of specific regions of the flow (formation length, layer thickness, virtual origins, wave length, etc.).

For each controlled experiment, including the synthetic data supplied by DNS, these quantitative data will give physical characteristics and invariants that have to be retrieved in the results of image sequence analysis. They will constitute the basis of a rigorous assessment of the reliability and accuracy of the different methods designed in the **FLUID** project along with their comparison with more classical measurement methods. Hot wire anemometry (1D to 3D) and PIV (2D and 3D) will be systematically used in order, on one hand, to allow comparisons with classical measurement means, and in the other hand to give physically consistent combinations of data for the assessment of the accuracy of the image sequence analysis results (see WP5). The workpackage has been divided in three tasks.

Task 1.1 : Selection of meteorological data The first task will consist in selecting a set of meteorological satellite image sequences displaying several well chosen meteorological events. This task will be achieved by Partner 6. It possesses a large database of such images acquired by different meteorological satellites.

Task 1.2: 2D controlled experimental and numerical data Diffusion of 2D experimental data to the partners involved in WP2 and WP3 will be carried out at the beginning of the project. In fact, a purely 2D turbulent flow is very difficult to obtain experimentally. In most experiments boundary conditions cannot be applied with a strict 2D conformation. The flow then develops local 3D characteristics and can only be considered as 2D by focusing on the mean velocity and mean fluctuations. Nevertheless there are at least two ways of obtaining images of a pure, or almost pure, 2D flows. The first way is to produce a numerical 2D simulation of a flow. This is feasible, for instance, for a plane mixing layer or for the wake of a cylinder. The second way is to carry out an almost 2D experiment and eliminate the possibility for the flow to develop the three-dimensional component (*i.e,* the stretching of vortices). Partners 4 and 5 will provide at the beginning of the project, the two types of 2D flow images. A first set of synthetic images can be rapidly extracted from a Direct Numerical Simulation of a plane mixing layer. More work has to be done to extract relevant physical data from the numerical results. A second set of images will also be available from an experiment carried out with nearly 2D conditions. Physical measurements have been performed in parallel to image acquisition, and statistics will be computed and delivered to the consortium. Partner 4 will, in addition, carry out specific experiments in a wind tunnel for two flow types :

- a plane mixing layer ;
- a cylinder wake.

For each type, conditions will be varied, in terms of mean velocity, velocity ratio and Reynolds numbers, to get a sufficiently wide range of conditions. Images and measurements will be selected in order to enable a 2D physical interpretation, with reliable information on discrepancies from pure 2D flows. Some data sets and images will be chosen specifically to evaluate to which extent each method remains reliable enough when slipping from 2D to 3D flow. Supplementary experiments or ajustments will be carried out if necessary according to the evaluation feedback provided by WP 5.

Task 1.3: 3D controlled experimental and numerical data This task will produce the data required by task 4.2, *i.e* 3D controlled images and physical data. 3D measurements (PIV and hot-wire) will be carried out on the two types of flow described above, in order to point out the 3D local behaviour of these globally 2D flows. Stereoscopic sets of images will be produced from a two-camera system. For the purpose of testing and validating 3D motion analysis on strongly three-dimensional flows, a third type of flow will be added by combining the shear flows of a mixing layer and a cylinder wake. Partner 4 has a strong experience of such kind of flows and will choose the relevant variables, invariants, and locations. Both 2D and 3D data will be delivered from this 3D flow, along with particular physical laws that can guide both the implementation and validation of 3D motion estimation. Other data sets will be selected by Partners 4 and 5 out of available databases on 3D flows, to enlarge the validation field of the techniques and allow comparison with PIV results.

Deliverables

D1.1 Report on selection of meteorological image sequence (Month 6).

D1.2 Report 1 on production and diffusion of fluid mechanics images and data (Month 12).

D1.3 Report 2 on production and diffusion of fluid mechanics images and data (Month 24).

D1.4 Final workpackage report (Month 36).

Risks and Contingency Plans Some images and data can rapidly be derived from previous experiments and numerical simulations already carried out by Partners 4 and 5. This ensures that there is no risk that achievement of WP1 delay the actual beginning of others workpackages. Difficulties may arise in a second phase, when the image production process will have to take into account the specific needs of the image analysis methods, as derived from the first tests. One of the objectives of the project is to design algorithms that can give a reliable motion estimation without needing too much specific lighting and seeding procedures. The need for exploratory tests on lighting and seeding may however appear for the evaluation of the sensitivity of algorithms to these parameters. It will be answered to that foreseeable need, firstly by generating sets of images with various lighting and seeding conditions (intensity, concentrations, generalised or local tracer feeding), and secondly by implementation of specific experimental procedures decided by the consortium.

Evaluation Criteria This work will be evaluated on the relevance of the images and data to describe the characteristics of the different types of flows, in order to allow a precise evaluation of the reliability and accuracy of the techniques developed. Furthermore, it will be evaluated on the ability of the data, and physical knowledge associated, to guide the implementation of the motion analysis methods.

Milestones and expected result

M1.1 First set of experimental and numerical images relative to 2D flows (Month 1)

M1.2 Complete set of numerical images and data describing a 2D mixing layer (Month 6)

M1.3 Complete set of experimental images and data describing a purely 2D flow (Month 6)

M1.4 First set of experimental images relative to a strongly 3D flow (Month 12)

M1.5 Complete set of experimental images and data describing a 2D flow with local 3D components (Month 18)

M1.6 Complete set of experimental images and data relative to a strongly 3D flow (Month 24)

M1.7 New images and data produced according to the need expressed by the consortium for final validations (Month 30)

WP 2: Physical models and early image processing

Lead Partner: 2

The objective of this workpackage is to design reliable and efficient algorithms for 2D motion estimation from fluid-flow image sequences. This workpackage will provides the technical and theoretical physical basis for subsequent fluid motion analysis (WP3) and 3D motion estimation (WP4).

The workpackage comprises the following tasks: **(2.2)** Multiscale *local* motion estimation and continuity equation evaluation; **(2.3)** Multiscale *global* motion estimation; **(2.4)** Motion estimation based on divergence–free and curl–free vector field components; **(2.5)** Multi-scale *numerical* motion estimation algorithms for sequential and parallel architectures.

Throughout the project task **(2.1)** has to be reconsidered: To what extent is it possible to incorporate physical models from fluid dynamics into computational approaches for motion estimation?

Task 2.1: Design of tractable applied physical models. In collaboration with fluid mechanics experts the impact of equations governing the dynamics of fluids will be assessed. This concerns local motion estimation (task 2.2) in terms of continuity equations as well as global 2D or 3D motion estimation in terms of appropriate priors (or regularizers; task 2.3). Moreover, properties like "incompressibility" naturally interact with corresponding decompositions of vector fields (task 2.4). The nature of the physical constraints retained will be of completly different nature in case of 2D or 3D motions. As a matter of fact, for 2D appparent motion the physical constraints have to be expressed as projection on the image plane. For 3D apparent motion the laws of fluid mechanics can be more narurally expressed.

Task 2.2: Efficient multiscale filter banks for pre-processing. Any motion estimation scheme has to represent time–varying image data in terms of local filters at multiple scales. Linear scale-space (i.e. Gaussian filters) are widely used in image processing. Recent progress concerning *uniqueness* in large motion estimation [11] and *efficiency* of dyadic tensor wavelet implementations [7] motivate to investigate the dis/advantages of alternative filter bank designs for local motion estimation.

Task 2.3: Multiscale motion field estimation. The filter banks considered in task 2.2 form a single component of approaches for *global* motion estimation at multiple scales. In addition, appropriate priors have to be investigated by taking into consideration both physical models of fluid dynamics and well-posedness of the resulting variational approach. Finally, the question of how to appropriately weight the prior (choice of the regularization parameter) is an important problem.

Task 2.4: Hodge decomposition and potential function estimation. The subsequent *analysis* of 2D and 3D fluid motion with respect to its *principal features* (see WP3) motivate to *estimate* fluid flow in terms of these features. A natural representation of vector fields in this respect is the Hodge decomposition [6]. The use of this representation for motion estimation while taking into account physical models (task 2.1) is an open point. The question of how to mathematically describe tractable computational models as feasibility problems with respect to related constraint sets has to be investigated in this context.

Task 2.5: Numerical aspects: Multigrid iteration, domain decomposition, and feasibility algorithms. Based on tasks 2.3 and 2.4, efficient implementations of the resulting numerical algorithms for 2D fluid flow estimation will be studied. This amounts to the design of adequate *numerical* multiscale schemes and its coupling with the filter stage from task 2.2. Furthermore, we will consider both *sequential* architectures (multigrid) and, if possible, *parallel* architectures (domain decomposition [15]). In the context of models for fluid dynamics, the latter is a highly non-trival task. Likewise, the design of convergent *parallel* algorithms for solving feasibility problems according to task 2.4 has to be investigated.

Deliverables

D2.1 Report on filter bank design for local fluid motion estimation (Month 12).

D2.2 Demonstrator on multiscale motion estimation (Month 12).

D2.3 Demonstrator on motion estimation based on the Hodge decomposition (Month 24).

D2.4 Demonstrator on multigrid multiscale motion estimation (Month 24).

D2.5 Report on motion estimation based on domain decomposition and feasibility algorithms (Month 33).

D2.6 Report summarizing the motion estimation approaches developped (Month 36)

Remark: The result of task 2.1 will be reported in connection with tasks 2.3 and 2.4.

Risks and Contingency Plans Tasks 2.3 and 2.4 depend on task 2.2, but not critically since Gaussian filters provide a reasonable starting point. Results of task 2.2 can then be used to produce improved input data for the approaches to be developed in tasks 2.3 and 2.4.

Task 2.4 is risky in the sense that is it not clear at present to what extent and in which situations decompositions of vector fields can be exploited to improve the estimation of fluid flow from image sequences. By contrast, task 2.3 is less risky and can be viewed as a save alternative and fallback position for task 2.4.

In task 2.5, the application of conventional multigrid is not risky. The development of domain decomposition techniques, however, is quite involved due to the potentially very complex interaction of operators acting on the regions and boundaries, respectively, of the subdomains. The study of feasibility algorithms depends on the result of task 2.4.

The whole workpackage depends on the compromise between physically meaningful and computationally tractable models to be studied in task 2.1.

In summary, this workpackage is structured along a less risky line of research (tasks 2.2, 2.3, 2.5 (multigrid)), and a more risky line of research (tasks 2.2, 2.4, 2.5 (domain decomposition, feasibility)). This structure makes sure that, at any rate, reliable input data will be provided for subsequent workpackages.

Evaluation Criteria This work will be evaluated on the basis of meteorological data and fluid flows experimental data. The evaluation process is described in the workpackage **5 Milestones and expected results**

M2.1 Implementation and evaluation of pre-processing filter stage for local 2D or 3D fluid motion estimation (Month 12).

M2.2 Implementation of multiscale 2D fluid motion estimation (Month 12).

M2.3 Design of motion estimation schemes based on the Hodge decomposition (Month 24).

M2.4 Implementation of multigrid multiscale motion estimation (Month 24).

M2.5 Design of domain decomposition schemes for fluid motion estimation. Study of feasibility algorithms for fluid motion estimation (Month 33).

WP 3: 2D Fluid motion analysis
Lead Partner: 1
Once a reliable description of the fluid motion is available, it is of primary interest to analyze it in order to extract its *principal features*. This leads for instance to identify and characterize the *critical* – or singular – points of the fluid flow. These points correspond to the centers of prominent kinematics structures such as *vortex, swirl*, or *sinks/sources* and serves as a basis of compact *phase portrait* descriptions of the flow [8]. The relation between the image data and such physical models is highly non-linear, which constitutes one of the main difficulties when one aims at detecting and tracking these entities along an image sequence. In this context we have to design a sophisticated and efficient non-linear *stochastic* filtering method. We will also have to consider complex fluid mechanics evolution models such as the Navier-Stokes equation (or at least an appropriate simplified version of this equation) instead of the usual dynamical models used in the computer vision community for object tracking. The workpackage will be subdivided into three tasks.

Task 3.1: Representation and segmentation of fluid flow structures. This task is concerned with the design of relevant parameterized representations of fluid motion fields. The most tractable and general ones are based on *analytical functions* or on *discrete particles system*. Our goal will be to propose methods to estimate their parameters from the computed velocity fields or directly from image intensities.

Task 3.2: Tracking of salient fluid flow structures. After estimating an appropriate representation of the velocity field at each time t the goal is to track the representative structure of the fluid flow over time. Both the likelihood term relating image measurements and motion models and the temporal evolution term expressing the *a priori* on the dynamics of these structures are likely to be non linear. This will lead us to deal with complex stochastic filtering that could be implemented with *particle filters* approach. Another crucial and difficult issue will be to propose physical tractable dynamical models to account for the evolution of fluid flow structures.

Task 3.3: Characterization of turbulent structures. An alternative approach to the ones described above is to directly detect global structures in fluid motions. This will require a deep understanding of the geometry of structures (both in still images and sequences) which will be gained by the collaboration with fluid mechanics experts. The proposed method should give quantitative results in terms of false alarm rate, which is a necessary condition for the efficiency of automatic surveillance algorithms. The input of such methods can either be the raw image sequences or the output of previous low level processing (**WP 2**).

Deliverables

D3.1 Paper on representation of the fluid flow structures(Month 12).

D3.2 Demonstrator on the fluid flow segmentation method (Month 18).

D3.3 Demonstrator on the tracking method (Month 33).

D3.4 Demonstrator on the turbulent structure characterization method (Month 33).

D3.5 Paper summarizing the approaches developed in this workpackage (Month 36).

Risks and Contingency Plans Methods developed in Task 3.1 and Task 3.3 will take as input a velocity field or directly the image intensities. The motion field representation is provided as output of tasks 2.2, 2.3 and 2.4 of WP 2, but could also be supplied as external data provided by PIV systems, standard motion estimators or even by meteorological institutes. Therefore, the availability of such data is not risky. As we plan to exploit stochastic filtering, task 3.2 depends on the definition of an appropriate and efficient dynamical model. Considering filtering as a fusion process, the better the conditional data likelihood and the dynamical model the more accurate the tracking. Nevertheless, the integration in standard tracking methods of a physically relevant fluid dynamical model should already improve the results of existing techniques.

Evaluation Criteria This work will be evaluated on the basis of meteorological data and fluid flows experimental data. The evaluation process is described in WP **5**.
Milestones and expected result

M3.1 Method for the estimation of the main structures of a fluid flow (Month 12)

M3.2 Design of appropriate dynamical models for tracking (Month 12)

M3.3 Implementation of linear trackers (Kalman filtering) to serve as a comparison basis

M3.4 Design of geometric criteria for the characterization of turbulent structures (Month 12)

WP 4: 3D Fluid motion estimation

Lead Partner: 3

One of the most exciting challenges in fluid imagery is to determine 3D measurements of fluid velocity from image sequences. This challenge is the aim of this workpackage. Techniques based on 3D Particle Image Velocimetry (PIV) have begun to be studied and developed in the flow visualization community. These techniques rely on stereoscopic extensions of 2D PIV systems and therefore suffer from the same drawbacks. In this workpackage, we propose to study computer vision techniques for the estimation of 3D velocities. The 3D aspect should additionally allow to include relevant fluid mechanics laws. This workpackage has been divided in two different tasks.

Task 4.1: Motion layers estimation and coupling This task aims at studying fluid which may be approximated as a succession of planar flows. The main target is in that case the atmospheric flow. We aim here at providing a description of different cloud-layers of the atmosphere from meteorological image sequences. The considered layers are situated at different altitudes and are moving with different motion. Due to the upward motion component these layers can not be considered as independent of each other. We have thus to face a global estimation problem. For meteorological image sequences, the infra-red thermal channel information which depends on the cloud altitude will be of great help to estimate a first partition into altitude layers. The second step will be to modelize the motion estimation problem as a statistical *finite mixture* estimation problem. The difficulties stand here in the modeling of the physical relations between layers and on the partially observable nature of the phenomena. As a matter of fact, layers are partially occluded at some places. As far as motion models are concerned, we plan to rely on the structural description provided by **task 3.1**. Such structural description will allow us to design tractable estimation methods providing an informative 3D-like motion fields (planar fields with attached altitude information) of atmospheric fluid flows.

Task 4.2: 3D stereoscopic motion estimation In this task the purpose is to devise actual 3D motion estimation of fluid flows. The methods under concern are usually extension of 2D methods to the third dimension. Stereoscopy is used to resolve the third component of velocity over a light sheet plane. Such a stereoscopic system differs from standard two-dimensional ones by the use of two cameras. Besides, the calibration parameters of the cameras are supposed to be known. The main difficulty again relies on the introduction of relevant tractable fluid mechanics constraints. Such methodology should enable within well founded variational framework to devise a stable and accurate method for 3D motion estimation. The estimation methods elaborated within that task will be mainly applied to experimental fluid flows.

Deliverables

D4.1 Demonstrator on the motion layers estimation method (Month 33).

D4.2 Demonstrator on the stereoscopic motion estimation method (Month 33).

D4.3 Paper summarizing the approaches developed in this workpackage (Month 36).

Risks and Contingency Plans The two tasks presented here are undoubtly very challenging both in an applicative prospect and in term of scientific issues. The goal is to evaluate to which extent computer vision techniques integrating fluid mechanics laws could outperform 3D extensions of PIV systems. Of course, such an integration involves difficult scientific modelization problems that we have to address and solve. From the point of view of robustness and accuracy, the achievement of these two tasks is highly risky. Nevertheless, we think that all the benefits could be gained from the 2D motion estimation tasks (2.2, 2.3 and 2.4) will be pass along the concerned tasks and will improve finally the results obtained by 3D PIV systems.

Evaluation Criteria The first task will be evaluated on the basis of meteorological data whereas the second task will be applied and evaluated both on meteorological data and on experimental fluid flows image. Comparizons with uptodate 3D PIV system will give us clear answers concerning the application of computer vision techniques to fluid flow analysis from images. The evaluation process is described in workpackage **5**.

Milestones and expected result

M4.1 Method for motion layers estimation without physical coupling between layers (Month 18).

M4.2 Extension of generic computer vision techniques for 3D motion estimation of fluid flows (Month 18).

M4.3 New method for motion layers estimation with the introduction of a an adapted coupling between layers (Month 36).

M4.4 New dedicated method for 3D motion estimation (Month 36).

WP 5: Experimental evaluation and physical interpretation of the results

Lead Partner: 6

The validation of the designed methods for fluid flow analysis is a crucial step of the project. It will allow us to assess the proposed solutions and to supply feedback to improve them. When initiating validation or revalidation, one of the most critical elements to be determined is the acceptance criteria to measure success. This will be accomplished in several ways, depending on the type of validation. The workpackage will be subdivided into four tasks following a process of validation. The references will be extracted from data obtained by correlation techniques (PIV or wind field estimator), Direct Numerical Simulation and Hot-Wire anemometry (1D-3D) (see workpackage 1).

Task 5.1: (Qualitative) Evaluation on meteorological data This task aims at giving a *qualitative* evaluation on meteorological data. The tasks of the workpackages 2, 3 and 4 will be evaluated on the basis of qualitative relevant criteria which rely on local and global physical characteristics and topology of the velocity fields (trajectories of characteristic points along the whole sequence, motion profil of vortices, etc...).

Task 5.2: Statistical evaluation of 2D/3D turbulent shear flows For this task, fluid mechanicians involved in the project will share their knowledge and expertise. A qualitative and quantitative validation of the fluid motion estimations will be caried out, based on the controlled 2D/3D experimental/numerical data provided by tasks 1.2 and 1.3. Concerning the qualitative approach, one will observe instantaneous vector fields. The comparisons between the estimates of fluid motion and the results provided by the PIV and Direct Numerical Simulations will be done on the following parameters : the velocity components u, v and w, the Div and $Curl$ fields and the spatial correlations (*i.e.* the observation of the vortices). The quantitative evaluation will be achieved using statistical criteria related to the flows. For 2D turbulence, one will compute velocity and vorticity statistics (velocity and vorticity increments) in the two-dimensional enstrophy cascade. For the plane mixing layer, one will calculate the parameters of the spreading of the flow as well as the Reynolds stress. For the wake of a cylinder, one will determine the mean wake flow characteristics (vortex formation length, recirculation bubble length, maximum intensity of the velocity fluctuations, Reynolds stress, mean velocity profiles...). For the interaction of the mixing layer with the wake of a circular cylinder, statistical values will be analysed in the plane of symmety of the wake.. All the tasks of the workpackages 2, 3 and 4 will be evaluated in a quantitative way on a large range of flow typologies.

Task 5.3: Evaluation and physical interpretation The results obtained in task 5.2 constitute a validation with respect to absolute references. Task 5.3 consists in *interpreting* the differences observed between the results obtained by the various methods developed in the **FLUID** project compared to those available in literature. The aim is to evaluate the *influence* of the physical models developed in the workpackage 2 (task 2.1 and 2.3), the *effectiveness* of the methods introduced in the workpackage 3 (parameterized representations, task 3.1; dynamical systems, task 3.2; geometry of structures, task 3.3) and the *capacity* to estimate 3D motion (3D-like motion fields, task 4.1 and 3D stereoscopic motion estimation task, 4.2). As a results, this task will allow us to improve the solutions developed in workpackages 2,3 and 4.

Task 5.3: Comparison with correlation techniques For the two principal applicative domains we will compare the diffferent motion fields obtained by the methods developped within this project with standard correlation techniques used in meteorology (wind field computation) or in experimental visualization (PIV technique).
This comparisons will be done on the basis of quantitative criteria. Discrepancies between the different methods will be reported and analysed. These comparisons will be done on instantaneous velocities and on complete trajectories of feature points. This will finally provide with comparisons in both *Eulerian* and *Lagrangian* representations.
The practical robustness of the different methods with respect to experimental conditions and requirements (seeding, lighting conditions, frame and image size, satellite chanels, velocity scale range) will be also systematically tested.

Deliverables

D5.1 Intermediate report on the evaluation of the taks of the workpackage 2 (Month 18).

D5.2 Intermediate report on the evaluation of the taks of the workpackage 3 (Month 21).

D5.3 Intermediate report on the evaluation of taks of the workpackage 4 (Month 24).

D5.4 Final report on the evaluation of the taks of the workpackage 2 (Month 27).

D5.5 Final report on the evaluation of the taks of the workpackage 3 (Month 30).

D5.6 Final report on the evaluation of the taks of the workpackage 4 (Month 33).

Risks and Contingency Plans This workpackage depends on all the others workpackages. Consequently the risk and the contingencies related to this workpackage are primarily inherited from the others workpackages. However, there is also specific risk to this workpackage. Indeed, the statistical evaluation (task 5.2) needs a certain amount of data to ensure good convergence properties of some indicators. The evaluation could therefore be delayed if supplementary results are needed to obtain accurate statistical estimates. Nevertheless, all the tasks of this validation process will provide a minimum of information which incontestably will contribute to a reliable evaluation of the methods developed.

Evaluation Criteria This work will be evaluated on the discriminant aspect of the different criteria used in this workpackage.
Milestones and expected result

M5.1 Feedback of informations for the improvements the taks of the workpackage 2 (Month 18)

M5.1 Feedback of informations for the improvements the taks of the workpackage 3 (Month 21)

M5.1 Feedback of informations for the improvements the taks of the workpackage 4 (Month 24)

WP 6: Management and Dissemination of Results
Lead Partner: 1

Specific objectives of WP6 are:

- To track the progress of milestones and deliverables against the project schedule, and where necessary to agree and implement changes in the workplan, to achieve the best attainable results for the overall project.
- To produce management and progress reports.
- To organize six meetings of the whole consortium during the three years project. Specific meetings concerning a subset of partners could also be settled when necessary on a given technical subject or for a given (subset of) workpackage(s).
- To insure that full advantage is taken of the opportunities to disseminate the project results.

Management; The project Leader will be the leader of WP 6. The whole consortium will meet every six month. The places chosen for the meeting will turn over the different partner localizations. These meetings will aim both at favoring the scientific exchanges and prospects of the different partners and at tracking the progress of the project against the schedule. The project schedule is indicated at the end of this section both in form of a complete deliverable list and as a PERT diagram and GANTT charts.

A **coordination assistant** at the coordinating site will be responsible for issues including interface with the commission; maintaining the project web page and related dissemination efforts; collecting, distributing and maintaining a data base of deliverables and reports; responding to enquiries about the project; meeting logistics.

Dissemination. The **FLUID** project consortium will devote significant effort to ensuring that full advantage is taken of opportunities for disseminating its results through active participation in the research and scientific communities. This will include publications of journal papers and in prestigious conferences such as European Conf. On Comp. Vision (ECCV), Int. Conf on Computer Vision (ICCV), Int. Conf on Image Proc. (ICIP), Int. Symp. on Flow Visualization (ISFV) and in specialized workshop such as the international Winds Workshop. The consortium plans to organize an open workshop on fluid motion analysis from images (with a call for papers) during the last year of the project. It will enable to highlight the main theoretical and applied results of the **FLUID** project, while gathering the most valuable contributions of other groups working on that domain or on related domains at an international level. It will offer a unique inter-disciplinary forum on flow visualization. Another route to dissemination will be through the website of the project, which will allow researchers to access publications arising from the work of the project, as well as giving access to concrete demonstrations of results obtained by the methods developed within the project. The applicative and industrial partners will also present demonstrations of the project results at exhibition concerned with experimental flow vizualisation.

WP6. has been broken down into 8 tasks:

Task 6.1-6.3: Year 1,2,3 management

Task 6.4-6.6 Annual progress reports

Task 6.7: Maintain project website and databases of dissemination efforts and deliverables.

Task 6.8 Organize 6 meetings on project results, scientific prospects and project management.

Task 6.9 Organize a workshop on fluid motion analysis from image sequences.

Deliverables

D6.1a Periodic Management Report 1: Month 6

D6.1b Periodic Management Report 2: Month 12

D6.2a Periodic Management Report 3: Month 18

D6.2b Periodic Management Report 4: Month 24

D6.3a Periodic Management Report 5: Month 30

D6.3b Periodic Management Report 6: Month 36

D6.4a Annual Progress report 1: Month 12

D6.4b Annual Progress report 2: Month 24

D6.4c Annual Progress report 3: Month 36

Risks and Contingency Plans. This project addresses challenging research issues involving substantial inter-dependency between partners. Some of the topics listed are ambitious and inevitably risky from a scientific point of view. Thus, there is the risk of slippage of some project results. Nevertheless, the most risky tasks from a scientific point of view, may always in the worst case be tackled with generic computer-vision techniques. The association of such approaches with adapted *prior* ensuing from fluid mechanics should improve the basic techniques. There is no risk that the most difficult tasks weaken the whole project. Annual meetings, will be the place where re-arrangements of the schedule, and if necessary implementation of contingency actions, will discussed and decided by a representation of the entire consortium. The workpackage leaders will then be in charge of implementating such actions.

Milestones and expected result

M6.1: Kick-of meeting devoted to scientific prospects and management of the project (Month 0)

M6.2: First year meetings on results, scientific prospects and management (around Month 6 and 12)

M6.3: Second year meeting on results, scientific prospects and management (around Month 18 and 24)

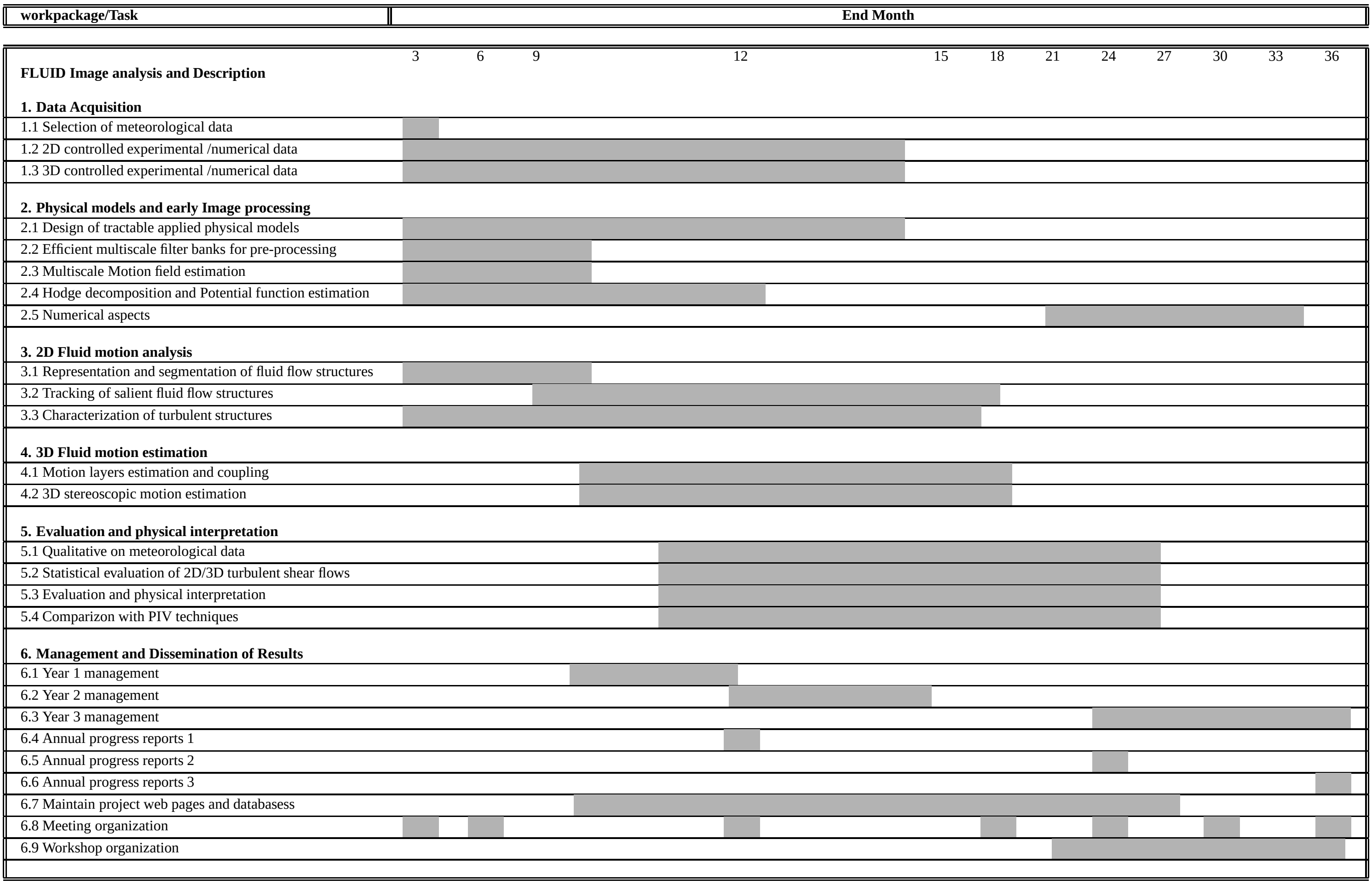
M6.4: Third year meeting on results (around Month 30 and 36)

M6.5: Workshop takes place (Around Month 30)

M6.6: Project complete (Month 36)

7.2 Planning and timetable

Project Plan (GANNT Chart)



7.3 Graphical presentation of workpackages

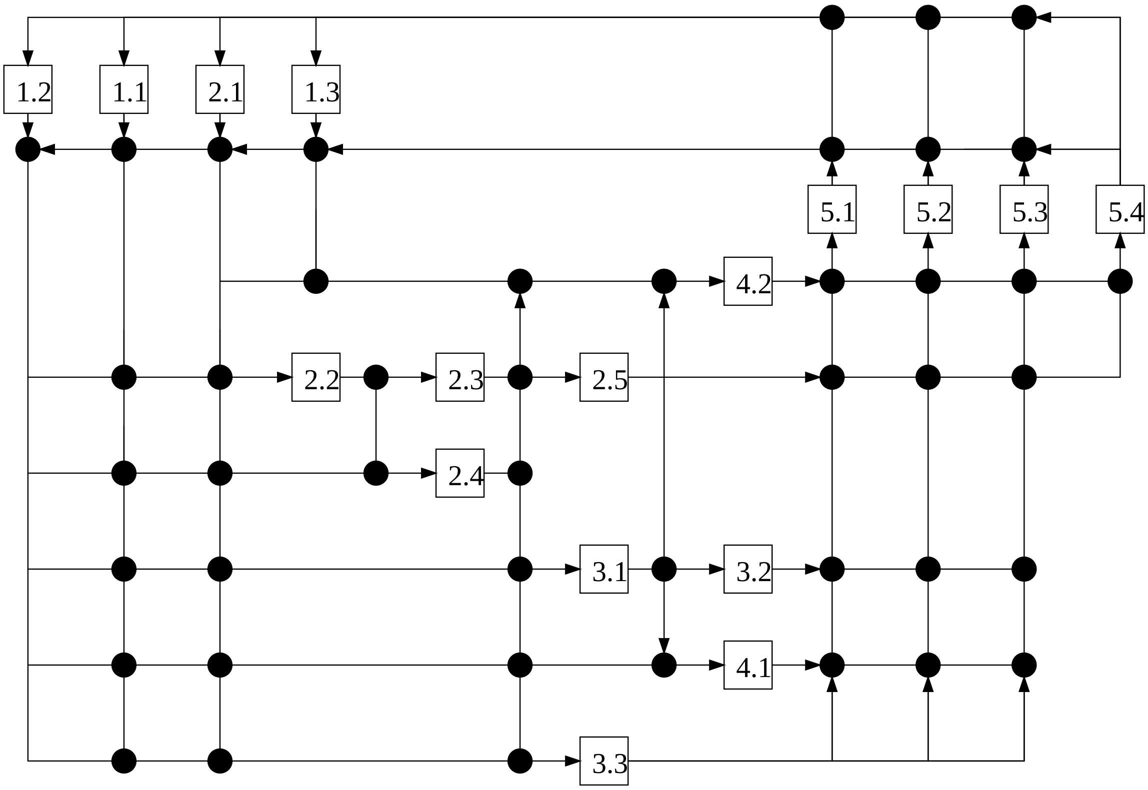


Figure 3: PERT diagram of the **FLUID** Workplan

7.4 Workpackages list

Worpackage list

Work package No	Workpackage title	Lead con-tractor No	Person-months	Start month	End month	Phase	Deliverable No
WP1	Data acquisition	4	21	1	30	R	D1.1–D1.3
WP2	Physical models and early Image processing	2	97	1	36	R	D2.1–D2.5
WP3	2D Fluid motion analysis	1	43.25	1	36	R	D3.1–D3.5
WP4	3D Motion field estimation	3	100	1	36	R	D4.1–D4.5
WP5	Evaluation and physical interpretation	6	56.75	1	36	R	D5.1–D5.4
WP6	Project Management and dissemination of results	1	12	1	36	-	D6.1–D6.4
	TOTAL		330				

7.5 Deliverables list

Deliverables list (sorted by delivery date)

Deliverable No	Deliverable title	WP no.	Lead participant	Estimated persons-month	Nature	Dissemination level	Delivery date
D1.1	Report on selection of meteorological sequences	1	6	2	R	PU	6
D6.1a	Periodic Management Report 1	6	1	1.5	R	PU	6
D2.1	Filter bank design for local fluid motion estimation	2	2	15.5	R	PU	12
D2.2	Multiscale motion estimation	2	3	19.4	D	PU	12
D6.1b	Periodic Management Report 2	6	1	1.5	R	PU	12
D3.1	Representation of fluid flow structures	3	1	2.5	R	PU	12
D1.2	Report 1 on production and diffusion of data	1	1	8.5	R	PU	12
D6.4a	Annual Progress report 1	6	1	1.25	R	PU	12
D3.2	Fluid flow segmentation method	3	1	12.75	D	PU	18
D5.1	Intermediate report on the evaluation of the taks of the workpackage 2	5	5	9.5	R	PU	18
D6.2a	Periodic Management Report 3	6	1	1.5	R	PU	18
D5.2	Intermediate report on the evaluation of the taks of the workpackage 3	5	6	9.5	R	PU	18
D2.3	Motion estimation based on Hodge decomposition	2	1	19.4	D	PU	24
D2.4	Multigrid multiscale motion estimation	2	2	19.4	D	PU	24
D5.3	Intermediate report on the evaluation of the taks of the workpackage 4	5	4	9.5	R	PU	24
D1.3	Report 2 on production and diffusion of data	1	1	8.5	R	PU	24
D6.2b	Periodic Management Report 4	6	1	1.25	R	PU	24
D6.4b	Annual Progress report 2	6	1	1.25	R	PU	24
D5.4	Final report on the evaluation of the task of the workpackage 2	5	5	9.5	R	PU	30
D5.5	Final report on the evaluation of the taks of the workpackage 3	5	6	9.5	R	PU	30
D6.3a	Periodic Management Report 5	6	1	1.25	R	PU	30
D2.5	Motion estimation based on domain decomposition and feasibility algorithm	2	2	19.5	R	PU	33
D3.3	Tracking method for fluid flows	3	1	12.75	D	PU	33
D3.4	Turbulent structures characterization method	3	1	12.75	D	PU	33
D4.1	Motion layers estimation method	4	1	45	D	PU	33
D4.2	Stereoscopic motion estimation method	4	3	50	D	PU	33
D5.6	Final report on the evaluation of the taks of the workpackage 4	5	4	9.25	R	PU	33
D2.6	Motion estimation techniques for fluid flows	2	1	3.9	R	PU	36
D3.5	2D motion analysis for fluid image sequences	3	1	2.5	R	PU	36
D4.3	3D and 2D$\frac{1}{2}$ motion estimation	4	2	5	R	PU	36
D1.4	Final workpackage report	1	1	2	R	PU	36
D6.3b	Periodic Management Report 6	6	1	1.25	R	PU	36
D6.4c	Annual Progress report 36	6	1	1.25	R	PU	36

7.6 Workpackage descriptions

Workpackage description

Workpackage number:	**1**	**Start date or starting event:**					**Month 1**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**0**	**0**	**0**	**14**	**5**	**2**	

Objectives Acquisition and selection of different kinds of data needed by the partners to implement and validate the developed methods. Data will be of several types : meteorological satellite images, numerical and experimental fluid flow vizualization data sequences, physical data from experimental measurements or numerical results (velocities, turbulence descriptors), computed data describing the flow in relation with fluid mechanics laws.

Description of work

Task 1.1: Selection of meteorological data.

Task 1.2: 2D controlled experimental and numerical data.

Task 1.3: 3D controlled experimental and numerical data.

Deliverables

D1.1 Report on selection of meteorological sequence (Month 6)

D1.2 Report 1 on production and diffusion of fluid mechanics images and data (Month 12)

D1.3 Report 2 on production and diffusion of fluid mechanics images and data (Month 24)

D1.4 Final workpackage report (Month 36)

Milestones and expected result

M1.1 First set of experimental and numerical images relative to 2D flows (Month 1)

M1.2 Complete set of numerical images and data describing a 2D mixing layer (Month 6)

M1.3 Complete set of experimental images and data describing a purely 2D flow (Month 6)

M1.4 First set of experimental images relative to a strongly 3D flow (Month 12)

M1.5 Complete set of experimental images and data describing a 2D flow with local 3D components (Month 18)

M1.6 Complete set of experimental images and data relative to a strongly 3D flow (Month 24)

M1.7 New images and data produced according to the need expressed by the consortium for final validations (Month 30)

Workpackage description

Workpackage number:	**2**	**Start date or starting event:**					**Month 1**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**13.5**	**39**	**24.5**	**4.75**	**4.5**	**10.75**	

Objectives The objective of this workpackage is to propose reliable and efficient algorithms for 2D motion estimation from fluid-flow image sequences. It thus provides the basis for subsequent fluid motion analysis (WP3) and 3D motion estimation (WP4). The methods will be assessed on meteorological and controlled experimental data

Description of work

Task 2.1: Design of tractable applied physical models.

Task 2.2: Efficient multiscale filter banks for pre-processing.

Task 2.3: Multiscale motion field estimation.

Task 2.4: Hodge decomposition and potential function estimation.

Task 2.5: Numerical aspects: Multigrid iteration, domain decomposition, and feasibility algorithms.

Deliverables

D2.1 Report on filter bank design for local fluid motion estimation (Month 12).

D2.2 Demonstrator on multiscale motion estimation (Month 12).

D2.3 Demonstrator on motion estimation based on the Hodge decomposition (Month 24).

D2.4 Demonstrator on multigrid multiscale motion estimation (Month 24).

D2.5 Report on motion estimation based on domain decomposition and feasibility algorithms (Month 36).

D2.6 Report summarizing the motion estimation approaches developped (Month 36)

Milestones and expected results

M2.1 Implementation and evaluation of pre-processing filter stage for local fluid motion estimation (Month 12).

M2.2 Implementation of multiscale 2D fluid motion estimation (Month 12).

M2.3 Design of motion estimation schemes based on the Hodge decomposition (Month 24).

M2.4 Implementation of multigrid multiscale motion estimation (Month 24).

M2.5 Design of domain decomposition schemes for fluid motion estimation. Study of feasibility algorithms for fluid motion estimation (Month 33).

Workpackage description

Workpackage number:	**3**	**Start date or starting event:**					**Month 1**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**26**	**6.75**	**6.25**	**1.75**	**1**	**1.5**	

Objectives To develop new methods for fluid motion analysis. New methods for tracking and characterization of representative fluid flows structures will be devised. These methods will rely on sensible and tractable physical laws provided by fluid mechanics expert. The methods will be assessed on meteorological and controlled experimental data

Description of work

Task 3.1: Representation and segmentation of fluid flow structures.

Task 3.2: Tracking of salient fluid flow structures.

Task 3.3: Characterization of turbulent structures.

Deliverables

D3.1 Paper on representation of the fluid flow structures(Month 12).

D3.2 Demonstrator on the fluid flow segmentation method (Month 18).

D3.3 Demonstrator on the tracking method (Month 33).

D3.4 Demonstrator on the turbulent structure characterization method (Month 33).

D3.5 Paper summarizing the approaches developed in this workpackage (Month 36).

Milestones and expected result

M3.1 Method for the estimation of the main structures of a fluid flow (Month 12)

M3.2 Design of appropriate dynamical models for tracking (Month 12)

M3.3 Implementation of linear trackers (Kalman filtering) to serve as a comparison basis

M3.4 Design of geometric criteria for the characterization of turbulent structures (Month 12)

Workpackage description

Workpackage number:	**4**	**Start date or starting event:**					**Month 1**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**20.5**	**0**	**68.5**	**4.75**	**4.5**	**1.75**	

Objectives To develop new methods for 3D fluid motion estimation. The methods we aim at devising will be of two different kinds. The first one will be devoted to flows that can be modelized as a succession of layers whereas the second kind of methods will be dedicated to real 3D velocity estimation. Both tasks will include general physical laws. The consideration of fluid mechanics laws should allow us to propose stable, accurate and relevant solutions in the fluid imagery context. These methods will be compared to results obtained by existing 3D PIV systems.

Description of work

Task 4.1: Motion layers estimation and coupling.

Task 4.2: 3D stereoscopic motion estimation.

Deliverables

D4.1 Demonstrator on the motion layers estimation method (Month 33).

D4.2 Demonstrator on the stereoscopic motion estimation method (Month 33).

D4.3 Paper summarizing the approaches developed in this workpackage (Month 36).

Milestones and expected result

M4.1 Method for motion layers estimation without physical coupling between layers (Month 18).

M4.2 Extension of generic computer vision techniques for 3D motion estimation of fluid flows (Month 18).

M4.3 New method for motion layers estimation with the introduction of a an adapted coupling between layers (Month 36).

M4.4 New dedicated method for 3D motion estimation (Month 36).

Workpackage description

Workpackage number:	**5**	**Start date or starting event:**					**Month 12**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**4**	**4.25**	**3.75**	**13.75**	**13**	**18**	

Objectives To provide qualitative elements of comparizon for meteorological image sequence; to carry out a statistical evaluation on 2D/3D shear flow on the basis of physical quantitative criterions; to evaluate in term of physical interpretations the methods developed.

Description of work

Task 5.1: (Qualitative) Evaluation on meteorological data.

Task 5.2: Statistical evaluation of 2D/3D turbulent shear flows.

Task 5.3: Comparison with correlation techniques (PIV and standard wind field estimation methods).

Deliverables

D5.1 Intermediate report on the evaluation of the taks of the workpackage 2 (Month 18).

D5.2 Intermediate report on the evaluation of the taks of the workpackage 3 (Month 21).

D5.3 Intermediate report on the evaluation of the taks of the workpackage 4 (Month 24).

D5.4 Final report on the evaluation of the taks of the workpackage 2 (Month 27).

D5.5 Final report on the evaluation of the taks of the workpackage 3 (Month 30).

D5.6 Final report on the evaluation of the taks of the workpackage 4 (Month 33).

Milestones and expected result

M5.1 Feedback of informations for the improvements the taks of the workpackage 2 (Month 18)

M5.1 Feedback of informations for the improvements the taks of the workpackage 3 (Month 21)

M5.1 Feedback of informations for the improvements the taks of the workpackage 4 (Month 24)

Workpackage description

Workpackage number:	**6**	**Start date or starting event:**					**Month 1**
Participant number:	**1**	**2**	**3**	**4**	**5**	**6**	
Person-months per participant	**12**	**0**	**0**	**0**	**0**	**0**	

Objectives To manage the project to optimize its success; to track the progress of milestones and deliverables against the project schedule, and where necessary to agree and implement changes in the workplan, to achieve the best attainable results for the overall project; to produce management and progress reports; to maintain the project web site and databases; to undertake dikssemination action; to organize a workshop on the project results.

Description of work
Task 6.1-6.3: Year 1,2,3 management.
Task 6.4: Author first annual progress report.
Task 6.5: Author second annual progress report.
Task 6.6: Author third annual progress report.

Deliverables
D6.1a: Periodic Management Report 1: Month 6
D6.1b: Periodic Management Report 2: Month 12
D6.2a: Periodic Management Report 3: Month 18
D6.2b: Periodic Management Report 4: Month 24
D6.3a: Periodic Management Report 5: Month 30
D6.3b: Periodic Management Report 6: Month 36
D6.4a: Annual Progress report 1: Month 12
D6.4b: Annual Progress report 2: Month 24
D6.4c: Annual Progress report 3: Month 36

Milestones and expected result
M6.1: Kick-of meeting devoted to scientific prospects and management of the project (Month 0)
M6.2: First year meetings on results, scientific prospects and management (around Month 6 and 12)
M6.3: Second year meeting on results, scientific prospects and management (around Month 18 and 24)
M6.4: Third year meeting on results (around Month 30 and 36)
M6.5: Workshop takes place (Around Month 30)
M6.6: Project complete (Month 36)

8 Project resources and budget overview

The consortium includes five academic research groups and one industrial group as described below. All the research groups are experienced, internationally known groups as attested in particular by the lists of selected references. They have contributed to numerous collaborative projects in the past. Each of them bring complementary interests and recognized experience in order to successfully achieve the **FLUID** project goals.

- **INRIA** will be the Project Leader and will lead WP3 and WP6. The Inria (French National Institute for Research in Computer Science and Control) team involved is the **VISTA**

("VIsion Spatio-Temporelle et Active") group situated in Rennes (France). This group is specialized in statistical modeling for image sequence processing and especially for visual motion analysis. Studies concerning fluid motion analysis have been one of its main subjects of investigation for several years. Research work on that topic focuses mainly on fluid motion estimation problems and on specific structure detection and tracking with important applications in the meteorological domain (which were supported by contracts with Meteo-France and Eumetsat) to estimate low clouds motion or to detect and track convective situations.

- **University of MANNHEIM** will lead WP2. The **CVGPR** Group of the Mannheim University (Germany) is concerned with various aspects of mathematical modeling and optimization for image processing. They have particularly studied issues of representation and processing of image sequences using partial differential equations, and problems of image segmentation using statistical shape knowledge.

- **University of LAS PALMAS** will lead WP 4. The **AMI** group of University of Las Palmas (Spain) mainly explores the applications of the mathematical analysis to a number of computer vision problems. The topic adressed includes morphological multiscale analysis and studies on partial differential equations for image processing and computer vision problems.

- **CEMAGREF** will lead WP1 and WP5. The Cemagref (French National Institute for Research in Agricultural and Environmental Engineering) team involved is the **AEROBIO** group situated in Rennes (France). It is involved in air flow research studies in the context of high care environment for industrial processes and rooms (e.g. food industry). From a methodological point of view, the group is specialized in experimental and numerical study of turbulent shear flows with an emphasis on mixing layers. Their goal will be to provide images from well controled experimental flows with known physical properties and evolution. They will also participate to the design of suitable physical models or constraints for fluid image processing.

- **LA VISION** is the industrial partner involved in WP1, WP2, WP4 and WP5. It is a German industrial company. It is specialized in the development of open PIV systems. Since a few years it has succeeded in becoming an unescapable reference in the domain of PIV visualization systems. Their task in the project will be to evaluate the new methods developed by the consortium against reference techniques used in the domain of flow visualization. It will also play a role of consultant in order to provide the consortium with real industrial needs and requirements.

- **LMD, CNRS** (Laboratory of Dynamic Meteorology) is situated in Ecole Polytechnique, Palaiseau, and in Ecole Normale Supérieure and University of Paris 6, Paris. LMD is involved in the study of the atmosphere and atmospheric processes. It is a renowned research laboratory in dynamical meteorology. The LMD gathers researchers specialized in atmospheric numerical modelization, climate processes as well as specialists of atmosphere observation through satellite images for the monitoring or forecasting of meteorological or pollution events.

  There is presently a renewed interest for tracking the air parcels both for studies of atmospheric pollution and for more general problems of transports in the atmosphere, particularly concerning water vapour. Model based analyses are frequently used for reconstructing these trajectories, but they need to be validated against observation. LMD will then

> provide relevant data of meteorological satellites, participate to the evaluation of the results of motions computed from these images, provide dynamical and physical constraints on the atmospheric fields, eventually deduced from models.

The groups forming the **FLUID** consortium have already experienced several fruitfull bilateral collaborations which took place either in informal context or within various contractual relations (see appendix A for details).

8.1 Efforts for the full duration of the project

STREP Project Form (person-months)
Full duration of project

WP no	WP title	INRIA	U. of Mannheim	ULPGC	CEMAGREF	La Vision	CNRS	Total Partners
	Research/innovation activities							
1	**Data acquisition**	0	0	0	14	5	2	21
2	**Physical models and early processing**	12	38	24	4	3	10	91
3	**2D Fluid motion estimation**	24	6	6	1	0	1	38
4	**3D Fluid motion estimation**	19	0	67	4	3	1	94
5	**Evaluation and Physical interpretation**	3	3	3	13	11	17	50
	Total research/innovation	58	47	100	36	22	31	294
	Demonstration activities							
2	**Physical models and early processing**	1.5	1	0.5	0.75	1.5	0.75	6
3	**2D Fluid motion estimation**	2	0.75	0.25	0.75	1	0.5	5.25
4	**3D Fluid motion estimation**	1.5	0	1.5	0.75	1.5	0.75	6
5	**Evaluation and Physical interpretation**	1	1.25	0.75	0.75	2	1	6.75
	Total demonstration	6	3	3	3	6	3	24
	Management activities							
6	**Management and dissemination of results**	12	0	0	0	0	0	12
	Total management	12	0	0	0	0	0	12
	TOTAL ACTIVITIES	76	50	103	39	28	34	330

8.2 Overall budget for the full duration of the project

Contract Preparation Forms

EUROPEAN COMMISSION

6th Framework Programme on
Research, Technological
Development and Demonstration

Specific Targeted Research or Innovation Project

as many copies of form A3.1 as necessary for the number of partners

Proposal Number	513663	Proposal Acronym	FLUID

Financial information - whole duration of the project

Partic pant	rganisatio short	Cost mode used	Estimated eligible costs and requested EC		osts and EC contribution per type of activitie			Total (4)=(1)+(2)+	Total receipts
					RTD or innovation	Demonstration activities (2)	Consortium Management		
4	CEMAGRE	FC		*Direct Costs (a)*	174 208,53	15 580,50	3 000,00	192 789,03	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	149 854,93	11 047,50	,00	160 902,43	
			costs	*Total eligible costs (a*	324 063,46	26 628,00	3 000,00	353 691,46	
			Requested EC contribution		162 031,73	9 319,80	3 000,00	174 351,53	
2	UNI MANN	AC		*Direct Costs (a)*	201 992,00	15 060,00	3 000,00	220 052,00	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	34 837,00	2 328,00	,00	37 165,00	
			costs	*Total eligible costs (a*	236 829,00	17 388,00	3 000,00	257 217,00	
			Requested EC contribution		236 829,00	17 388,00	3 000,00	257 217,00	
6	CNRS	FCF		*Direct Costs (a)*	329 868,61	18 000,00	3 000,00	350 868,61	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	63 406,87	3 000,00	,00	66 406,87	
			costs	*Total eligible costs (a*	393 275,48	21 000,00	3 000,00	417 275,48	
			Requested EC contribution		196 637,74	7 350,00	3 000,00	206 987,74	
5	LAVISION	FCF		*Direct Costs (a)*	147 955,93	28 200,00	3 000,00	179 155,93	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	21 800,00	5 040,00	,00	26 840,00	
			costs	*Total eligible costs (a*	169 755,93	33 240,00	3 000,00	205 995,93	
			Requested EC contribution		84 877,97	11 634,00	3 000,00	99 511,97	
3	ULPGC	FCF		*Direct Costs (a)*	359 000,00	13 200,00	3 000,00	375 200,00	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	71 018,87	2 130,57	,00	73 149,44	
			costs	*Total eligible costs (a*	430 018,87	15 330,57	3 000,00	448 349,44	
			Requested EC contribution		215 009,43	5 365,70	3 000,00	223 375,13	
1	INRIA	FC		*Direct Costs (a)*	224 406,85	31 212,67	56 425,34	312 044,86	,00
			Eligibl	*of which subcontracti*	,00	,00	,00	,00	
				Indirect costs (b)	239 943,35	29 020,27	58 040,54	327 004,16	
			costs	*Total eligible costs (a*	464 350,20	60 232,94	114 465,88	639 049,02	
			Requested EC contribution		232 175,10	21 081,53	75 300,00	328 556,63	
TOTAL			Eligible costs		**2 018 292,94**	**173 819,51**	**129 465,88**	**2 321 578,33**	**,00**
			Requested EC contribution		**1 127 560,97**	**72 139,03**	**90 300,00**	**1 290 000,00**	

8.3 Management level description of resources and budget

The ressources needed to carry on the project in term of personnel and equipment are listed below. For each of the partners we give also the cost corresponding to the different categories of personns involved in the FLUID project. All the costs, are total costs and include the overhead costs.

- **Partner 1, VISTA group, INRIA**
  Personnel ressources

  - 76 man-month 594 049 Euros

  Persons involved

  - **Patrick Bouthemy**, DR1 INRIA,
  - **Frédéric Cao**, CR1 INRIA,
  - **Etienne Mémin**, Maîtres de Conférence, Rennes I university,
  - **1 PHD student**,
  - **1 Ingenior**.

  The ingenior will be involved both in demonstration activities and in management activities.

- **Partner 2, CVGPR group, University of Mannheim**
  Personnel ressources

  - 50 man-month 232 217 Euros

  Persons involved

  - **Christoph Schnoerr**, Professor,
  - **1 PHD student**.

- **Partner 3, AMI group, university of Las Palmas de Gran Canaria**
  Personnel ressources

  - 103 man-month 426 349 Euros

  Persons involved

  - **Luis Alvarez**, Catedràtico Universidad,
  - **Luis Mazorra**, Catedràtico Universidad,
  - **Javier Sanchez**, profesor Asociado,
  - **2 PHD student**,
  - **1 Ingenior**.

- **Partner 4, AEROBIO group, CEMAGREF**
  Personnel ressources

  - 39 man-month 331 691 Euros

Persons involved

- **George Arroyo**, confirmed scientist,
- **Dominique Heitz**, confirmed scientist,
- **J. Carlier**, scientist,
- **L. Wallien**, scientist,
- **P. Georgeault**, technician
- **P. Loubat** , technician

- **Partner 5, LaVision GmbH**
  Personnel ressources

  - 28 man-month 244 560 Euros

  Persons involved

  - Dr. Heinrich Voges R&D Manager,
  - Uwe Dierksheide Project Manager,
  - 1 Engineer.

  Equipment ressources

  - **3D-PIV system:** 20000 Euros

- **Partner 6, LMD, CNRS**
  Personnel ressources

  - 34 man-month 395 275 Euros

  Persons involved

  - André Szantai, IE,
  - Michel Desbois, DR1,
  - Alain Lahellec, IR2,
  - G. Seze CR1,
  - 1 research Ingenior.

Ethical issues form

A. Proposers are requested to fill the following table

Does your research raise sensitive ethical question related to:	**YES**	**NO**
Human Beeing		X
Human biological samples		X
Personal data (whether identified by name or not)		X
Genetic information		X
Animal		X

B. Proposers are requested to confirm that the proposed research does not involve:

Research activity aimed at cloning for reproductive purposes.
Research activity intended to modify the genetic heritage of human beings which could make such changes heritable.
Research activity intended to create human embryos solely for the purpose of research or for the purpose of stem cells procurement, including by means of somatic cell nuclear transfer. Research activity involving the use of human embryos or embryonic stem cells with the exeption of banked or isolated embryonic stem cells in culture

Confirmation: the proposed research involves none of the issues listed in section B	**YES**	**NO**
	X	

SIXTH FRAMEWORK PROGRAMME
PRIORITY IST
FET - Open Domain

Contract for :

SPECIFIC TARGETED RESEARCH PROJECT

Appendix A - Consortium description

Acronym: FLUID

Project full title: FLUid Image analysis and Description

Proposal/ Contract number: FP6-513663

Related to other Contract no.: n/a

Date of preparation of Annexe I: 05/10/2004

Operative commencement date of contract:

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The groups forming the **FLUID** consortium have already experienced several fruitfull bilateral collaborations which took place either in informal context or within various contractual relations.

- The VISTA group, and the CVGPR group have collaborated together within the French-German collateral collaboration program "PROCOPE". These two groups have experienced various visiting scientist exchanges during 2 years. Several collaborative works have been published:
  - T. Kohlberger, E. Mémin, C. Schnoerr. Variational dense motion estimation using a DIV-CURL higher order regularization. In Int. Symp. on Signal Processing and Its Applications, *ISSPA'03*, Paris, France, 2003.
  - T. Kohlberger, E. Mémin, C. Schnoerr. Variational dense motion estimation using the Helmholtz decomposition. *Scale Space 03*, L.D. Griffin, M. Lillholm (eds.), Lecture notes in computer science, Volume 2695, Pages 432-448, Isle of Skye, UK, June 2003.
- The LMD and the VISTA group have both participated to a two years EUMETSAT project on wind field estimation (1998-2000).
  - Désalmand F., M. Desbois, P. Lecomte, A. Szantai, P. Bouthémy, E. Mémin, P. Perez and S. Zimeras, 2000, Satellite-derived atmospheric motion vectors improved displacement estimates of low-level clouds over land. EUMETSAT contract number EUM/CO/99/699/KTH, 98 p.
- CEMAGREF and the VISTA group have collaborated whithin a national grant. This project focused on flow visualization for food industry.
  - T. Corpetti, E. Mémin, A. Santa-Cruz, D. Heitz, G. Arroyo. Optical flow estimation in experimental fluid mechanics. *Seventh Int. Symp. on Signal Processing and its Applications*, ISSPA'03, Paris, France, July 2003.

There have been also numerous individual cintact between the different members of the consortium. These exchange occured in particular for several Ph-D thesis defences:

- Luis Alvarez (AMI group) was examiner of the Ph-D thesis of Thomas Corpetti and of the "habilitation" of Etienne Mémin (VISTA group).
- Michel Desbois (LMD) was examiner of the PHD thesis of Christophe Papin (Vista group).
- Patrick Bouthemy (VISTA group) was examiner of Andre Szantaï (LMD) Ph-D thesis.
- Etienne Mémin was examiner of Javier Sanchez Ph-D thesis (AMI group).

To achieve the goals of the **FLUID** project, the **expertise and resource** in the following fields are brought by the different partners:

- imaging devices and data collecting (controlled experimental data from the selected application fields);
- design of appropriate fluid mechanics models and physical models;
- image sequence analysis (statistical-, and PDE–based computational methods);
- evaluation of results and comparison to current available up to date PIV systems.

The relationships between these items are illustrated in Fig.4. All these required expertise and resource are brought by the **FLUID** partners. Furthermore, the **FLUID** project will combine the considerable and complementary inter-disciplinary expertise of its partners in a way that is not possible in any individual country because of the limitations of available skill-sets and budgets. A central and novel aspect of the **FLUID** project is the **inter-disciplinary collaboration** between researchers in **applied fluid mechanics, flow visualization, dynamical meteorology, applied mathematics and computer vision**. Only few studies on the subject exist in different scientific areas, yet the mandatory interaction between different disciplines for a deeper study and innovative solutions is lacking. The **FLUID** project also involves both research groups (Inria, Univ. Mannheim, Univ. Las Palmas, Cemagref, LMD), end-users (Cemagref, LMD) and providers (LaVision) in that domain.

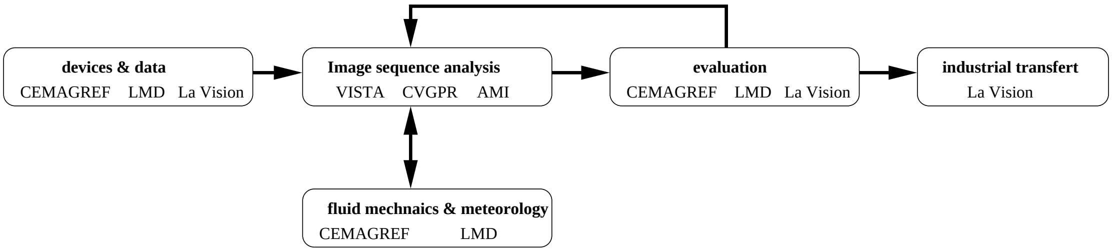

Figure 4: Combined expertise of the **FLUID** consortium

Detailed description of the participants

Partner #1

Name of the group: Vision Spatio-Temporelle et Active (VISTA)
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The VISTA group is an INRIA research team which focuses on image sequence analysis and computer vision problems. INRIA (Institut National de Recherche en Informatique et en Automatique) is a national public research organism in Computer Science and Control. IRISA, which is the Inria site in Rennes, is composed of 25 research groups and comprises more than 400 people including about 120 Ph-D students. It is concerned with fundamental and applied computer science, automation and information processing. It is also supported by the national research organism CNRS, and by the University of Rennes.

The VISTA group includes about 30 persons (6 Inria full-time researchers, 2 CNRS full-time researcher,1 Assistant Professor, 1 Inria Engineer, 13 Ph-D students, 4 Post-doc). Fields of interest are mainly two-fold: (i) Analysis of image sequences according to statistical approaches (Markov models, robust estimators, particle filtering, . . .), with an emphasis on (rigid, deformable and fluid) motion analysis and tracking. (ii) Active vision based on a visual servoing approach. We are dealing with several application domains : video indexing, meteorology, medical imaging, robotics, sonar, experimental visualization in fluid mechanics, transportation. Modeling and analysis of visual motion, and more generally of dynamic phenomena, has been thoroughly investigated by VISTA group for the last decade. The VISTA group is internationally recognized for its contributions in motion analysis, embrassing motion modeling, motion detection, motion estimation, motion segmentation, motion recognition, and tracking. For fluid motion analysis, the VISTA group has proposed innovative methods. Our work in that domain has in particular benefited from long-term and close collaborations with various European or French meteorological organizations : EUMETSAT (contract), Météo-France (contract and Ph-D thesis), and the LMD (Laboratoire de Météorologie Dynamique). The designed method for 2D fluid velocity field computation was a first attempt to incorporate some knowledge from fluid mechanics and it enables to recover fluid flow velocities with a high accuracy compared to usual techniques. The corresponding software has been transferred to Eumetsat to be tested on a large scale for wind field computation. It has also been utilized by the AEROBIO group of the CEMAGREF for the evaluation of different kinds of flows and compared with 2D PIV technique.

The **FLUID** project will take profit from the experience and the results gained by VISTA group in those different collaborations as well as from its academic skills in statistical image sequence modeling and motion analysis.

People involved in the proposal

Patrick Bouthemy graduated from ENST, Paris, in 1980, and received the Ph.D degree from the University of Rennes, France, in 1982. Since April 1984, he has been with INRIA, at IRISA in Rennes. He is currently "Directeur de Recherche" Inria and head of VISTA group. His major research interests are: statistical approaches for image sequence processing, motion analysis, tracking, motion recognition and classification. He has been involved in several European projects. The most recent ones are the DIVAN project ("Distributed audio-Visual Archives Network"), the CARSENSE project ("Sensing of Car Environment at Low Speed Driving"), the on-going LAVA project ("Learning for Adaptable Visual Assistants"). He serves as an Associate Editor of the IEEE Transactions on Image Processing. He has been member of the program committee of all the major international conferences in image processing and computer vision (ECCV, CVPR, ICCV, ICPR, ICIP). He is author of more than 120 papers, including more than 30 articles in image processing or computer vision international journals. Supervisor of about 20 Ph-D theses.

Frédéric Cao graduated from the École Polytechnique (Paris, France) in 1995. In 1996, he obtained the DEA of Numerical Analysis in University of Paris VI (Jussieu). He then prepared a PhD thesis (defended in January, 2000) in the École Normale Supérieure de Cachan, with Jean-Michel Morel as advisor. He was with the Délégation Générale pour l'Armement (French Armament Agency) from 2000 to 2001, and joined IRISA in September 2001. His research interests are partial differential equations, mathematical morphology, object tracking, detection theory.

Etienne Mémin received the PhD degree in computer science in 1993 and the "habilitation" degree in 2003 from the university of Rennes I, France. From 1994 to 1999, he was assistant professor in computer science at the University of South Brittany (UBS Vannes). He is currently assistant professor in computer science at the University of Rennes I. His major research interest concerns motion analysis (motion estimation, motion segmentation and tracking), energy based modeling and parallel processing. Since a couple of years, he is particularly interested in motion analysis issues for image sequences depicting fluid phenomenon.

References

[1] E. Arnaud, E. Mémin and B. Cernuschi-Frias. Conditional filters for image sequence based tracking - application to point tracker. *IEEE Trans. on Image Processing*, accepted for publication.

[2] P. Bouthemy, A. Benveniste. Modeling of atmospheric disturbances in meteorological pictures. *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 6(5):587-600, Sept. 1984.

[3] P. Bouthemy, E. François. Motion segmentation and qualitative dynamic scene analysis from an image sequence. *Int. Journal of Computer Vision*, 10(2):157–182, April 1993.

[4] F. Cao and L. Moisan. Geometric computation of curvature driven plane curve evolution. *SIAM J. Numer. Anal.*, 39(2):624–646, 2001.

[5] F. Cao. *Geometric curve evolution and image processing*. Lecture Notes in Mathematics, Springer Verlag, 2003.

[6] T. Corpetti, E. Mémin, P. Pérez. Dense estimation of fluid flows. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 24(3):365-380, March 2002.

[7] T. Corpetti, E. Mémin, P. Pérez. Adaptation of standard optic flow methods to fluid motion. *Int. Symposium on Flow Visualization*, Edinburgh, August 2000.

[8] Corpetti, E. Mémin, P. Pérez. Extraction of Singular Points from Dense Motion Fields: an Analytic Approach. *Journal of Mathematical Imaging and Vision*, 19(3):175-198, 2003.

[9] R. Fablet, P. Bouthemy, P. Pérez. Non-parametric motion characterization using causal probabilistic models for video indexing and retrieval. *IEEE Trans. on Image Processing*, 11(4):393-407, April 2002.

[10] P. Hellier, C. Barillot, E. Mémin, P. Pérez. Hierarchical estimation of a dense deformation field for 3D robust registration. *IEEE Transactions on Medical Imaging*, 20(5):388-402, May 2001.

[11] M. Maurizot, P. Bouthemy, B. Delyon. Direct localization, motion characterization, and tracking of centers of atmospheric disturbances in Meteosat image sequences. *The Eumetsat Meteorological Satellite Data Users' Conference, EUMETSAT'97*, Brussels, Oct. 1997.

[12] M. Maurizot, P. Bouthemy, B. Delyon. 2D fluid motion analysis from a single image. *IEEE Int. Conf. on Computer Vision and Pattern Recognition, CVPR'98*, pages 184-189, Santa Barbara, June 1998.

[13] E. Mémin, P. Pérez. Optical flow estimation and object-based segmentation with robust techniques. *IEEE Trans. on Image Processing* 7(5):703-719, May 1998.

[14] E. Mémin, P. Pérez. Fluid motion recovery by coupling dense and parametric fields. *IEEE Int. Conf. on Computer Vision, ICCV'99*, Volume 1, pages 620-625, Corfu, Greece, September 1999.

[15] E. Mémin, P. Pérez. Hierarchical estimation and segmentation of dense motion fields. *Int. Journal of Computer Vision*, 46(2), Febrary 2002.

[16] J.-M. Odobez, P. Bouthemy. Robust multiresolution estimation of parametric motion models. *Journal of Visual Communication and Image Representation*, 6(4):348-365, December 1995.

[17] C. Papin, P. Bouthemy, E. Mémin, G. Rochard. Tracking and characterization of highly deformable cloud structures. *European Conf. on Computer Vision, ECCV'2000*, Dublin, June 2000.

[18] C. Papin, P. Bouthemy, G. Rochard. Unsupervised segmentation of low clouds from infrared METEOSAT images based on a contextual spatio-temporal labeling approach. *IEEE Trans. on Geoscience and Remote Sensing*, 40(1):104-114, January 2002.

[19] J.-N. Provost, C. Collet, P, Rostaing, P. Pérez, P. Bouthemy. Hierarchical Markovian segmentation of multispectralimages for the reconstruction of water depth maps. *Computer Vision and Image Understanding*, to appear 2004.

[20] Y. Ricquebourg, P. Bouthemy. Real-time tracking of moving persons by exploiting spatio-temporal image slices. *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 22(8):797-808, August 2000.

Partner #2

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The University of Mannheim (UMA) is a young university with about 11.000 students. It is located in the center of a large conurbation of Germany, the “Rhein-Neckar region”.
The chair for Computer Vision, Graphics, and Pattern Recognition (CVGPR) was founded in 1999 as part of the Mathematics and Computer Science Department. Research focuses on computer vision problems placing emphasis on variational models, advanced nonlinear and combinatorial optimization techniques, and corresponding algorithm design.
The CVGPR–group currently comprises 12 PhD–students based on grants from the German National Science Foundation (DFG) and industry. Since its foundation in 1999, the group received several awards from the German Association for Pattern Recognition (DAGM), and a best student paper award at the IEEE Workshop on Variational and Level Set Methods in Computer Vision (Vancouver, 2001). A summary of recent research results follows:

Optic flow estimation. Based on our previous work [1, 2, 3, 4], spatio–temporal variational models [5] as well as a taxonomy of convex (data-driven, flow-driven, isotropic, and anisotropic) regularizers [6] have been provided for variational optic flow estimation, including extensions beyond the standard Sobolev space framework [7]. First steps towards efficient numerical schemes [8, 9] and higher-order regularization flow estimation [10] have been made.

Variational segmentation and statistical shape priors. A novel diffusion–based snake model has been developed by incorporating statistical shape knowledge into the variational approach of Mumford-Shah for image segemntation [11]. In order to encode non-linear statistics of shapes, shape vectors are represented by means of reproducing kernel Hilbert spaces [12]. This has also been applied to motion estimation [13]. Recent work focuses on integration of shape-priors and level-set based segmentation [14] as well as general models for statistical image appearance [15].

Mathematical programming for partitioning, grouping and matching. Research in the CVGPR-group also addresses sound mathematical programming approaches to difficult non-convex and combinatorial optimization problems of image processing and computer vision. Recent work includes variable embedding and conic programming for binary partitioning, grouping and weighted graph matching [16, 17] as well as dc-programming for 3D-recovery from small-angle projections [18].

People involved in the proposal

Christoph Schnörr received the Dipl.-Ing. degree in Electrical Engineering (1987), the Dr. degree in Computer Science (1991), both from the Technical University of Karlsruhe, and the Habilitation degree in Computer Science (1998) from the University of Hamburg, Germany. He held positions from 1987–1992 as a researcher for image sequence analysis at the Fraunhofer Institute for Imformation and Data Processing (FhG-IITB, Karlsruhe), and from 1992-1998 as

a researcher and assistant professor (1995) within the Cognitive Systems Group at the University of Hamburg. During 1996 he was a visiting researcher at the Computer Vision and Active Perception Laboratory at KTH (Stockholm, Sweden). Since Oct. 1998, he is with the Dept. of Mathematics and Computer Science at the University of Mannheim where he set up and is heading the CVGPR–group.
Dr. Schnörr served as area-chair in connection with ICCV'03 and is member of the Editorial Boards of the *J. of Math. Imaging and Vision* and the *Int. J. of Computer Vision* (since this year). He is interested in computer vision, pattern recognition, and related aspects of mathematical modeling and optimization.

References

[1] C. Schnörr. Determining optical flow for irregular domains by minimizing quadratic functionals of a certain class. *Int. J. of Comp. Vision*, 6(1):25–38, 1991.

[2] C. Schnörr. Computation of discontinuous optical flow by domain decomposition and shape optimization. *Int. J. of Comp. Vision*, 8(2):153–165, 1992.

[3] C. Schnörr. Segmentation of visual motion by minimizing convex non-quadratic functionals. In *12th Int. Conf. on Pattern Recognition*, Jerusalem, Israel, Oct 9-13 1994.

[4] C. Schnörr, R. Sprengel, and B. Neumann. A variational approach to the design of early vision algorithms. *Computing Suppl.*, 11:149–165, 1996.

[5] J. Weickert and C. Schnörr. Variational optic flow computation with a spatio-temporal smoothness constraint. *J. Math. Imaging and Vision*, 14(3):245–255, 2001.

[6] J. Weickert and C. Schnörr. A theoretical framework for convex regularizers in pde–based computation of image motion. *Int. J. Computer Vision*, 45(3):245–264, 2001.

[7] W. Hinterberger, O. Scherzer, C. Schnörr, and J. Weickert. Analysis of optical flow models in the framework of calculus of variations. *Numer. Funct. Anal. Optimiz.*, 23(1/2):69–89, 2002.

[8] A. Bruhn, J. Weickert, C. Feddern, T. Kohlberger, and C. Schnörr. Real-time optic flow computation with variational methods. In N. Petkov and M.A. Westenberg, editors, *Proc. Computer Analysis of Images and Patterns (CAIP'03)*, volume 2756 of *LNCS*, pages 222–229. Springer, 2003.

[9] T. Kohlberger, C. Schnörr, A. Bruhn, and J. Weickert. Domain decomposition for parallel variational optical flow computation. In B. Michaelis and G. Krell, editors, *Pattern Recognition, Proc. 25th DAGM Symposium*, volume 2781 of *LNCS*, pages 196–203. Springer, 2003.

[10] T. Kohlberger, E. Mémin, and C. Schnörr. Variational dense motion estimation using the helmholtz decomposition. In L.D. Griffin and M. Lillholm, editors, *Scale Space Methods in Computer Vision*, volume 2695 of *LNCS*, pages 432–448. Springer, 2003.

[11] F. Cremers, D. and Tischhäuser, J. Weickert, and C. Schnörr. Diffusion snakes: Introducing statistical shape knowledge into the mumford–shah functional. *Int. J. Computer Vision*, 50(3):295–313, 2002.

[12] D. Cremers, T. Kohlberger, and C. Schnörr. Shape statistics in kernel space for variational image segmentation. *Pattern Recognition*, 36(9):1929–1943, 2003.

[13] D. Cremers and C. Schnörr. Statistical shape knowledge in variational motion segmentation. *Image and Vision Comp.*, 21(1):77–86, 2003.

[14] D. Cremers, N. Sochen, and C. Schnörr. Towards recognition-based variational segmentation using shape priors and dynamic labeling. In L.D. Griffin and M. Lillholm, editors, *Scale Space Methods in Computer Vision*, volume 2695 of *LNCS*, pages 388–400. Springer, 2003.

[15] M. Heiler and C. Schnörr. Natural statistics for natural image segmentation. In *Proc. IEEE Int. Conf. Computer Vision*, pages 1259–1266, Nice, France, Oct. 13-16 2003.

[16] J. Keuchel, C. Schnörr, C. Schellewald, and D. Cremers. Binary partitioning, perceptual grouping, and restoration with semidefinite programming. *IEEE Trans. Patt. Anal. Mach. Intell.*, 25(11):1364–1379, 2003.

[17] C. Schellewald and C. Schnörr. Subgraph matching with semidefinite programming. In *Proc. Int. Workshop on Combinatorial Image Analysis (IWCIA'03)*, Palermo, Italy, May 14-16 2003.

[18] T. Schüle, C. Schnörr, S. Weber, and J. Hornegger. Large-scale discrete tomography by convex-concave regularization and d.c. programming. Comp. science series, technical report, Dept. Math. and Comp. Science, University of Mannheim, Germany, October 2003. *Discr. Appl. Math.*, submitted.

Partner #3

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The University of Las Palmas de Gran Canary (ULPGC) is located at the Canary Islands in Spain. The ULPGC has currently more than 20.000 students in many different domains, such as computer science, medicine, architecture, languages, etc... The mathematical analysis of images (AMI) research group belongs to the computer science department at the ULPGC. The AMI research group has been created in 1991. The main goal of this research group is to explore the applications of the mathematical analysis to computer vision. Currently, the group AMI is composed of 4 seniors researchers, and 5 doctoral students, they have all permanent positions at the ULPGC.

During the last 10 years we have accumulated a certain experience and expertise in computer vision. We have developed some fruitful relations with several research groups mainly in Europe, in particular, with the CEREMADE laboratory (Univ. Dauphine in Paris), the Ecole Normale de Cachan (France), INRIA (Sophia-Antipolis), etc . . . We have addressed different problems in computer vision and our main contributions to the field are the following :

- Morphological multiscale analysis. Using an axiomatic approach, we studied the multiscale analysis which satisfy a number of geometric, morphological and architectural invariances. We have shown that these new multiscale analysis, generated by Partial Differential Equations (PDE) are very useful to address some computer vision problems such as shape representation or singular points extraction.
- Image enhancement, image quantization, denoising, image filtering. We have designed new PDE's based models to address various classical computer vision problems such as image enhancement (shock filter approach), image quantization (reaction-diffusion equation), denoising (anisotropic diffusion type equations), image filtering (efficient approximation of linear Gaussian filter have been designed).
- Optic flow estimation. We have proposed a new variational approach to the problem of optic flow estimation for large displacements. Some improvements have been also considered in order to deal with occlusion areas and to estimate an invertible motion field.
- 3-D geometry reconstruction. We have introduced a new model for dense disparity map estimation. We designed a new technique for multiple camera calibration based on a morphological extraction of singular points. With these methods, the 3D geometry reconstruction of the scene is estimated with a high accuracy.
- Fourier descriptors in computer vision. We have proposed a new sequence of filters to estimate the edge point orientations. Using Fourier analysis and the edge orientation information, we have built some new techniques to address issues such as shape representation, object motion tracking and texture discrimination.
- XMegaWave. We have also created a window oriented image processing software named XMegaWave which includes most of the algorithms we have developed in the last years.

People involved in the proposal

Luis Alvarez has received a M.Sc. in applied mathematics in 1985 and a Ph.D. in mathematics in 1988, both from Complutense University (Madrid, Spain). Between 1991 and 1992 he worked as post-doctoral researcher at CEREMADE laboratory. Currently, he is full professor at ULPGC. He is the foundator and scientific leader of the AMI group. He is an expert in computer vision. He is in the editorial board of the journal JMIV and in the main conference in the computer vision area (ICCV, ECCV, CVPR, Scale-Space, ect..). He has been the scientific in charge by the ULPGC in 2 HCM European projects: "Mathematical Modelling of Image Processing" (Ref.: ERBCHRXCT930095) and "Viscosity solutions and their applications" (Ref.: ERB-4061-PL-97-0777). Both projects were mainly concerned with the training of young researchers.

Javier Sánchez has received a M.Sc. in computer science in 1997 from the ULPGC. Between october 1997 and february 1998, he obtained an ERASMUS grant to follow some courses of the DEA 127 "Informatique: Systemes Intelligents" at the University Paris IX. He has also spent several months in the Robotvis project at INRIA (Sophia-Antipolis) working with Rachid Deriche. He is currently assistant professor at the ULPGC. He has recently obtained the doctoral degree under the supervision of Professor Luis Alvarez . His main area of interest is optic flow and disparity map estimation using a variational approach, on this topic he has published some papers in the main journals on this fields like IJCV or JVCIR. He has participated in the HCM european project "Viscosity solutions and their applications" (Ref.: ERB-4061-PL-97-0777

References

[1] L.Alvarez, P-L.Lions and J-M.Morel. Image selective smoothing and edge detection by nonlinear diffusion *SIAM J. on Numerical Analysis.* Vol. 29, No. 3, pp. 845-866, 1992.

[2] L.Alvarez, F.Guichard, P-L.Lions and J-M.Morel. Axioms and fundamental equations of image processing. *Arch. for Rational Mechanics*, Vol. 123, No. 3 pp. 199-257, 1993

[3] L.Alvarez and L.Mazorra. Signal and image restoration using shock filters and anisotropic diffusion, *SIAM J. on Numerical Analysis.* Vol. 31, No. 2 pp. 590-605, 1994.

[4] L. Alvarez and J-M.Morel. Formalization and computational aspects of image analysis. *Acta Numerica*, Cambridge University Press, pp. 1-59,1994

[5] L.Alvarez and J-M Morel. A Morphological Approach to Multiscale Analysis. From Principles to equations. *Geometry-Driven Diffusion in Computer Vision*, Ed. B.Romeny, Kluwer Academic Publishers, 1994

[6] L.Alvarez and F.Morales. Affine morphological multiscale analysis of corners and multiple junctions. *International Journal of Computer Vision*,. Vol. 25, Nž 2 pp91-105, 1997

[7] L.Alvarez and J.Esclarín. Image quantization using reaction-diffusion equations. *SIAM Journal on Applied Mathematics*, 57 N:1, pp. 153-175. 1997

[8] L.Alvarez J.Weickert and J.Sánchez. A Scale-Space Aproach to Nonlocal Optical Flow Calculations, *ScaleSpace'99*. Ed. M.Nielsen, P.Johansen, O.Olsen and J.Weickert, pp.235-246 Lectures Notes in Computer Science Nž 1682. Springer, 1999

[9] L.Alvarez J.Weickert and J.Sánchez. Reliable Estimation of Dense Optical Flow Fields with Large Displacements, *International Journal of Computer Vision*, 39(1), 41-56, 2000

[10] L.Alvarez, R.Deriche, J.Sánchez and J.Weickert. Dense Disparity Map Estimation Respecting Image Discontinuities : A PDE and Scale-Space Based Approach. INRIA technical report Nž 3874. To appear in *Journal of Visual Communication and Image Representation*.

Partner #4

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The Cemagref AEROBIO group is a research team of CEMAGREF, which is a national public research institute dedicated to agricultural and environmental engineering. Cemagref has 900 employees, 450 of whom are engineers and research workers. About one hundred fifty PhD students and three hundred long-term trainees are present at the institute at any time. The Aerobio group comprises 9 persons (3 researchers, 2 engineers, 2 technicians and 2 Ph-D) and is part of the Food Process Engineering Research Unit (30 persons) situated in the Cemagref site of Rennes.

It is involved in researches on airflow in industrial processes and rooms, particularly in high-care environments, mainly for hygiene applications in the food industry. It has recently carried out investigations on localised air handling systems, designed to deliver ultraclean air flows over a restricted area around the food products to be manufactured. As fully closed systems cannot be used in many industrial situations, the research has been focused on the problems associated with open systems where the volume protected by a clean airflow is not physically separated from the ambient air. In such situations, the main challenge is to limit the transfer of pollutants through the free interface between the clean airflow and the polluted ambient air, taking into account the presence of obstacles like the operators' arms. This topic has been extended to the broader question of controlling localised airflow in industrial environments in order to minimise the transfer of particles, gaseous pollutants or heat, between the ambient air and a restricted area protected by a controlled forced airflow. To cope with that problem, the group has developed an approach based on experimental and numerical fluid dynamics applied to the study of turbulent free shear flows, particularly mixing layers, alone or in interaction with obstacle wakes. Experimental studies are carried out in wind tunnels, using hot wire anemometry, flow visualisation and Particle Image Velocimetry (PIV). For flow visualisation and analysis, encouraging trials have been made with the methods developed by the VISTA group of INRIA. They appear to be particularly promising to measure and analyse the details of velocities, vortices and coherent structures at different scales, and scalar fields in regions where the instabilities give rise to large scale structures present in nominally forced 2D flows up to fully 3D turbulent flows.

In the **FLUID** project, the AEROBIO group will bring its ability to:

- produce different types of images of 2D or 3D flows in wind tunnels and in experimental or industrial air handling devices;
- participate to the application of the motion analysis methods, proposed by the other partners, both on real images and on virtual images from numerical simulations;
- participate to the physical interpretation of the motion analysis results, as well as to the implementation of physical models into the image analysis methods.

People involved in the proposal

Georges Arroyo is graduated from ENGEES Strasbourg and ENSP Rennes in 1976, and received the Ph-D degree in bioprocess engineering from INSA Toulouse (National Institute of Applied Sciences), France in 1992. He has been working in Cemagref from 1981 to 1986 on hydraulic and bioprocesses for the treatment of liquid wastes, then from 1986 to 1991 in INSA Toulouse on fluid mechanics applied to tangential filtration in bioprocesses, and again in Cemagref from 1992 to 2002 on air quality and airflow management in the food industry. He is attached to Cemagref by the French Ministry of Agriculture as a research engineer, and is presently head of the Aerobio team. His research interests are experimental and numerical fluid mechanics applied to the development of ultraclean air handling systems for the food industry.

Dominique Heitz received the PhD degree in Aerodynamic and Fluids Mechanics from the University of Poitiers, France, in 1999. He joined the Cemagref in 1999, has a permanent position and is currently "Chargé de Recherche" Cemagref. In 2000 he participated to the NATO Advanced Study Institute–European High Level Scientific Conferences (Session LXXIV New trends in turbulence). His research interests deal with turbulent shear flows, low velocities, numerical approach (DNS, LES), experimental approach (hot-wire anemometry, PIV, visualizations) and flow control. He is in charge of the fundamental part of the research for the ultra-clean protection engineering research.

References

[1] G. Arroyo., P. Marchal. Procédé et dispositif de protection rapprochée d'un plan de travail au moyen d'un flux d'air propre. PATENT nř96 07961, 25 p, 1996.

[2] D. Heitz, J. Delville, G. Arroyo, J.-H. Garem, J.-P. Bonnet, and P. Marchal. Interaction of the wake of a circular cylinder and a plane mixing layer. In *TSF 11'th*, volume 1, pages 5.1–5.6, Grenoble - France, September 8–10 1997.

[3] D. Heitz, J. Delville, G. Arroyo, J.-H. Garem, J.-P. Bonnet, and P. Marchal. Turbulent plane mixing layer perturbed by the wake of a circular cylinder. In Uriel Frisch, editor, *Advances in Turbulence VII*, pages 309–312. Kluwer Academic Publishers, 1998.

[4] D. Heitz, G. Arroyo, J. Delville, J.-H. Garem, P. Marchal, and J.-P. Bonnet. Wake caracteristics modifications with a plane mixing layer. In *35 Colloque d'Aérodynamique Appliquée - Analyse et Contrôle des Ecoulements Turbulents*, pages 1.100–1.107, Lille, 22–24 Mars 1999. Association Aéronautique et Astronautique de France.

[5] G. Arroyo, D. Heitz. Analysis and control of localised air flows to improve hygienic food manufacturing and packaging. *Int. Symp. On Food Factory of the Future*, p 129, Gothenburg, Sweden, June 2001.

[6] C. Braud, D. Heitz, P. Braud, G. Arroyo and J. Delville. Investigation of plane mixing layer – wake interaction by means of 2D planes PIV and POD *11'th International Symposium - Application of Laser Techniques to Fluids Mechanics*, Lisbon, July 2002. Submitted

[7] C. Braud, D. Heitz, G. Arroyo, J. Delville and J.-P. Bonnet. Low-dimensional Galerkin model of a plane mixing layer-wake interaction. *In Turbulent Shear Flow Phenomena-3*, Sendai, Japon, June 2003.

[8] P. Parnaudeau, D. Heitz, E. Lamballais and J.H. Silvestrini. Combination of the immersed boundary method with compact schemes for DNS of flows in complex geometry. In *Direct and Large Eddy Simulation-5*, Munich, Germany, August 2003.

[9] C. Braud, D. Heitz, P. Braud, G. Arroyo and J. Delville. 3D POD analysis of a mixing-layer wake interaction by means of two 2D PIV planes. *Experiments in Fluids*, 2004, to appear.

[10] C. Braud, D.Heitz, G. Arroyo, L. Perret, J.Delville, J. P. Bonnet,. Low-Dimensional Analysis, using POD, for two mixing layer - wake interactions, *International Journal of Heat and Fluid Flow*, to appear 2004.

Partner #5

Name of the group LaVision
Organization: LaVision GmbH
Address: Anna-Vandenhoeck-Ring 19, D-37081 Goettingen, Germany
Web page: http://www.lavision.de

Company Profile:

LaVision, founded in 1989 with now more than 40 employees, is an innovative driven, high-tech company providing state-of-the-art CCD based camera systems and customer specific turn-key optical measurement systems for particle detection, spray characterization, flow visualization, combustion research, and more. LaVision's product range includes visualization systems for particle laden flows, spray characterization, PIV (Particle Image Velocimetry) systems for planar velocity measurements.
In the field of optical flow measurements, the stereo PIV technique has recently become established as the most viable one to acquire 3-component flow velocity data in a single plane. LaVision is the leading company in Europe for the distribution and development of this technique. With strong ties to numerous university and other research groups - being part of many national and international projects - the task of LaVision has been to transfer the latest state-of-the-art experimental techniques into commercial products of high quality and ease-to-use.

Contribution to the project:

1. Consulting: image processing algorithm applied in practice, what kind of information is required and should be extracted from the images.
2. Feeding the project with real images which cannot be analyzed sufficiently with current techniques.
3. LaVision will supply and/or develop software and hardware for test measurements and comparison.

Contact persons for the project

Bernhard Wieneke: Bernhard Wieneke, M.Sc. has been working for LaVision since more than 10 years. As head of the software development department, he has been responsible for the development of the PIV algorithms and software package which incorporates more than 20 men-years of work. He is a specialist for digital image processing algorithms as well as camera and optic hardware. Recently, he has been applying the basic PIV correlation technique to material science 2D- and 3D- deformation measurements.

Uwe Dierksheide: Dipl. Phys. Uwe Dierksheide joining LaVision in 1994 is responsible for the PIV-group. He is a specialist for all experimental aspects of PIV measurements, developing advanced hardware and optics like miniature endoscopes. Currently, he is involved in different projects together with other European research groups concerning biomedical applications of the PIV technique.

Partner #6

Name of the group : CNRS/IPSL/Laboratoire de Météorologie Dynamique
Organisation : LMD is a mixed unity of Research (UMR) depending on CNRS, Université de Paris 6, Ecole Polytechnique, and Ecole Normale Superieure. It is part of a federation of laboratories IPSL, mainly specialized in Climate studies.
Address : LMD, Ecole Polytechnique, 91128 Palaiseau Cedex
Web pages : http://www.lmd.polytechnique.fr
Director : Hervé Le Treut
Tel : 01 69334553
Fax : 01 69333005

LMD was originally founded in 1968 by Pierre Morel in order to use emerging techniques of space observation and numerical modelization for the study of the atmosphere and atmospheric processes. Three of its first realizations where the EOLE experiment, using balloons located by satellite to study the trajectories of air parcels in the high troposphere, the development of a Global atmospheric model, and the contribution to the launch of the METEOSAT program, for which a prototype radiometer was developed in LMD. Pioneer studies of cloud motions on the first geostationary pictures of the Earth in order to retrieve winds were also conducted in LMD. Keeping its specialities of space observation of the atmosphere and modelisation, LMD was then mainly oriented towards climate processes studies in the frame of the climate change which is now observed. A theoretical group working on atmospheric turbulence also developed. Concerning motion detection and atmospheric trajectories studies, the specialty of tracking motions on satellite images, as well as studies done with balloons following the atmospheric flow, were kept alive. More recently, trajectories took another interest for the tracking of water vapour (both on satellite images and models) and for the study of atmospheric pollution at various scales. One team of LMD is actively involved in the real time monitoring and forecasting of pollution events in the Paris area. Studies of the atmospheric boundary layer are also conducted from surface remote sensing systems (lidars, radars, radiometers) located on the Palaiseau site. For climate research, LMD is associated with other laboratories specialized in relevant domains as oceanography, atmospheric chemistry, in the frame of the IPSL, a federation of institutes. LMD has a permanent staff of more than 100 people (50 researchers, 50 technical and administrative) + more than 50 non-permanent : PhD students, limited duration contracts, visitors. The main group of LMD participating to the proposal is the CET group (Tropical Water and Energy Cycle) headed by Michel Desbois. This group uses mainly the tools of satellite meteorology and climate, but is also related to modeling teams of LMD. The CET group has an average size of 15 members, including 10 researchers and engineers, and 5 doctorate students and temporary staff. The research subjects are centered on the water cycle in the atmosphere, including studies of water vapour, clouds, precipitation, radiative budget and associated processes and dynamics. In the submitted proposal the role of LMD will be :

- To chose and provide sequences of meteorological satellites images on which the determination of motions or trajectories is particularly interesting or presenting specific problems.
- To analyse the results of the processing of these sequences in terms of meteorology, to validate them by comparisons to model meteorological analyses and to results of conventional or operational methods as those used in EUMETSAT.
- To provide physical constraints to the methods for retrieving fields of motions, these constraints being derived from the experience of LMD in dynamics of the atmosphere, turbulence and modeling.

People involved in the proposal

André Szantai is "docteur de l'Université de Paris 6" (1996) and is specialized in the analysis of cloud and atmospheric motions on geostationary satellite images. He is permanent engineer in CNRS/LMD since 1985. He published several papers on this subject and participated regularly to the international workshops on the subject, gathering all the big meteorological and space institutions working on it.
Michel Desbois is docteur ès sciences (1974) and now Research Director in CNRS/LMD. He always worked on satellite meteorology and climatology and heads the CET group of LMD. He collaborated to several international space programs and field experiments. He always had contacts and collaborations with the European organization for meteorological satellites (EUMETSAT). He also promoted national

satellite programs in the frame of CNES. He is presently involved in the development of data bases dedicated to "Clouds, aerosols, radiation and water cycle" and in the next big international experiment "AMMA" about the African Monsoon, which requires the intensive use of many satellite data, due to the poor surface measurement network.

Alain Lahellec (graduated from Sup'Elec 1969) is a research engineer at LMD since 1990. He is contributing to the development of LMDZ, the atmospheric General Circulation Model of the Institut Pierre Simon Laplace. He directed a thesis in applied fluid dynamics (A.Rodrigues, Paris XI, 1996) and one on an the application of satellite imagery to model evaluation (A. Mathieu, Paris VI, 2000).

References

[1] Arnaud Y., M. Desbois and J. Maizi. Automatic tracking and characterization of African convective systems on Meteosat pictures. *Journal of Applied Meteorology*, 31, 443-453 1992.

[2] Désalmand, F., A. Szantai and M. Desbois. an attempt to retrieve low cloud motion winds over land in the African monsoon flow on Meteosat Pictures. *Geophys. Res. Lett.*, *26*, 3, 319-322, 1999.

[3] Désalmand F., M. Desbois, P. Lecomte, A. Szantai, P. Bouthémy, E. Mémin, P. Perez and S. Zimeras, 2000, Satellite-derived atmospheric motion vectors improved displacement estimates of low-level clouds over land. EUMETSAT contract number EUM/CO/99/699/KTH, 98 p.

[4] Désalmand, F., A. Szantai, L. Picon and M. Desbois. Systematic observation of westwards propagating cloud bands over the Arabian Sea during INDOEX from METEOSAT-5 data. *J. Geophys. Res* (in press).

[5] Jobard, I., and M. Desbois. Satellite estimation of the tropical precipitation using the METEOSAT and SSM/I data. *Atmospheric Research*, 34, 285-298, 1993.

[6] A. Mathieu, Lahellec A., Weill A. Evaluation of a Numerical Weather Forecast Using Boundary Layer Cloud-Top Temperature Retrieved from AVHRR. 14pp, in press, Mon. Wea. Rev. 2004.

[7] Picon, L., and M. Desbois. Relation between Meteosat water Vapor radiance fields and large scale tropical circulation features, *J. Climate*, 3, 865-876, 1990

[8] Roca, R., L. Picon, M. Desbois, H. Le Treut and J.-J. Morcrette, 1997 Direct Comparison of METEOSAT Water Vapor Channel Data and General Circulation Model Results. *Geophys. Res. Lett.*, 24, 147-150, 1997

[9] Roca, R., M. Viollier, L. Picon and M. Desbois A Multi Satellite Analysis of Deep Convection and its Moist Environment over the Indian Ocean during the Winter Monsoon. *J. Geophys. Res*, 2002.

[10] A.M.Rodrigues, Canha da Piedade A., Lahellec A. Grandpeix J.Y. Modelling natural convection in a heated vertical channel for room ventilation. *Building and Environment* 35, 455-469, 2000.

[11] Szantai A., M. Desbois, and F. Désalmand. A method for the construction of cloud trajectories from series of satellite images. International. *J. Remote Sensing*, 23, 8, 1699-1732, 2001.

[12] Szantai,A., F. Désalmand, and M. Desbois, Monitoring the life cycle of cirrus clouds using Meteosat-4 data during ICE-1989. *Meteorol. Appl.*, 8, 153-168, 2001.

A.2 Sub contracting

We do not foresee any new participants or scientific sub-contracting over the course of three years.

A.3 Other countries, industrial and other partners

The consortium does not include any participants outside of the EU members and associated states.

A.4 Funding of third country participants

n.a.