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DETECTING AND TRACKING OF MESOSCALE OCEANIC FEATURES IN THE MIAMI ISOPYCNIC CIRCULATION OCEAN MODEL

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Abstract

Using the available data from MICOM for the North Atlantic, in this paper we present methods developed to automatically detect, locate and track mesoscale eddies spatially and temporally. Using structuring elements based on velocity we detect eddy centers and use streamline plots to eliminate false positives. Additional visualization, based on the detected eddy centers provides information about the eddies temporally and spatially. The process of identifying and tracking oceanic eddies over space and time, and their relationship to the net poleward heat transport are of fundamental importance for Climate studies. Multiple visualizations resulting from this project will provide oceanographers an invaluable tool to assess mesoscale oceanic features.

Key Words – Scientific Visualization, Eddy Detection and Tracking, Physical Oceanography.

1. Introduction

The poleward heat transport by the oceans and the atmosphere is an essential process to maintaining the global climate in equilibrium. The heat transport due to mesoscale eddy fluxes needs to be realistically included to quantify the poleward heat transport of the ocean [1]. To understand the role of these structures in the heat transport, methods of automatically detecting and tracking these structures are needed. In this paper we focus on the problem of detecting mesoscale eddies. Due to the enormity of the high-resolution ocean data, computation is expensive both in terms of computing power and time (on top of the added space complexity to this problem). This leads to use of the low-resolution data for quick understanding of the system behavior. While the low-resolution data is considerably smaller in quantity, it also lacks the quality of information ordinarily available in the high-resolution data. In [2] we took two metrics from Physical Oceanography, poleward heatflux and eastward heatflux. The heatfluxes provide a measure of the heat transport poleward and eastward for each latitude and longitude respectively. While this is a very important metric, it is difficult to visualize. In order to better visualize the heat transport we broke the metrics down to their fundamental components to define new metrics, *heat index*. With this metric we were able to visualize the heat transport by breaking down the magnitude and encoding the direction of heat flow. The visualization of heat transport, poleward and eastward, paved the way for the identification and detection of mesoscale features. While the long-term goal of this project is to study the effects of heat transport by the mesoscale features, we build on our earlier work and confine our attention to the automatic detection and tracking of mesoscale eddies. The rest of the paper is organized as follows - the introduction is followed by previous work in this area, then a brief introduction to the dataset is provided, followed by a discussion of the motivation for this study, the following section addresses the method and algorithm used in this work, followed by results and conclusions.

2. Previous work

This section highlights some of the work in the general area of ocean-data visualization and recent research work on eddy detection techniques for oceanic datasets.

Prior to the availability of advanced visualization techniques, ocean model outputs were visualized in 2D rectangular flat surfaces. In order to render such output more realistically, various techniques have emerged. These included digital elevation models, wire frame overlays, and grayscale and color-shading mapping techniques [3]. A tool called Oceanographic Visualization Interactive Research Tool (OVIRT) has been developed to explore the utility of scalar field volume rendering in visualizing environmental ocean data and to extend some of the classical 2Doceanographic displays into a 3D visualization environment [4]. Visualization techniques used for ocean data have included - trivariate (B-Splines) parametric representation of data [5], feature-extraction and tracking [6], feature based visualization for tracking sea surface temperature [7], and measurement and analysis of feature velocities (usually referred to as estimation of optic flow).

To assess the role of oceans in maintaining the global heat balance, three methods have been used in the recent years [1]. One of these is the direct method, which deals with the product of ocean velocity and temperature measured over the boundaries of a closed volume. These are integrated to determine the ocean heat transport divergence for the volume. One of the concerns while doing the direct estimates of the ocean heat transport is the role of eddy fluxes and the validity of the circulation scheme. Our ultimate goal is to be able to understand the role of eddies by detecting and following them in. Here we summarize other recent studies that involve eddy detection, numerically as well as using remotely sensed data.

In recent numerical studies, synthetic floats have been released in an ocean general circulation models. One such paper studies fluid pathways followed by the upper limb of the Atlantic Ocean meridional overturning circulation (MOC) [8]. Observationally, eddies are ubiquitous feature of the circulation in the ocean, e.g. southeastern Bering Sea [9]. Bering Sea eddies have been detected by the near-circular trajectories of satellite-tracked drifting buoys that were entrained within them or from radially symmetric geostrophic velocity cross sections inferred from water density as measured by CTD casts.

Eddy detection is also frequently done for the remotely sensed data. Continuous observations since 1991 by using the synthetic aperture radar (SAR) aboard the Almaz-1, ERS-1/2 and RADARSAT satellites have shown that oceanic eddies are distributed worldwide in the ocean. Typical vortex motion in the ocean visible in the optical, IR and SAR satellite imagery [10]. This paper presents the Space/time and kinematic characteristics of different vortical types. Manifestations of the oceanic eddies allow the retrieval of the eddy parameters such as dimensions, rotation direction, spiraling order, lifetimes, temperature contrasts and chlorophyll/suspend matter concentration. Another recent study concerns the Caribbean TOPEX/POSEIDON altimetry data [11] spanning 3 years. These were processed and compared to ERS data, Geosat data, and an Atlantic Ocean model simulation. Due to limited altimeter data in the south because of topography interference, 14^o North latitude was studied extensively. Ten distinct anticyclonic eddies and ten less distinct cyclonic eddies propagating westward and growing were observed corresponding well with the 6 over 2 years seen using Geosat data.

3. Motivation

Mesoscale eddies and jets in the ocean are thought to be important contributors to poleward heat transport. Numerical eddy resolving ocean models are often used to quantify this important contribution, since trans-oceanic sections require large resources (e.g. the World Ocean Circulation Experiment). While this heat transport can be quantified by looking at various heat flux components across a zonal-cross section (constant latitude sections), it can also be quantified in models by tracking heat transport due to eddies temporally and spatially. The traditional method used by oceanographers [12] of computing oceanic heat transports is quite useful, but does not track the lifetimes and transports of individual eddies. We would eventually like to examine the heat transport by the eddies by an alternate method -- by tracking individual eddies, their contribution to the poleward heat transport with time and by temporally tracking these individual contributions to examine the life-cycles of the eddies that are found to be important for their contribution to the poleward heat transport. These diagnostics, which by design ultimately agree with the traditional method, also provide an insight into the numerical model, to see if the individual eddy lifetimes and heat transport agree with the theoretical ideas for the mesoscale eddies being shed by baroclinic instability. Our approach therefore uses ideas from scientific visualization to detect and track mesoscale eddies in a particular MICOM simulation.

4. Numerical General Circulation Model: MICOM

MICOM is the Miami isopycnic ocean circulation model, which uses density as a vertical coordinate for the ocean. In this model, the data is saved at different spatial and temporal (i.e. varying depth) locations in the ocean. Typically the data is collected daily (or every three days) for 6 or 12 months at a time. Each data set has multiple variables associated with them, such as velocity, temperature, salinity etc. The data available to us is in two resolutions. The high-resolution data is usually $1/12^{th}$ of a degree longitude by $1/8^{th}$ of a degree latitude by 35 layers. The finest resolution studies contrast strongly with the low resolution and show particularly turbulent behavior [13].

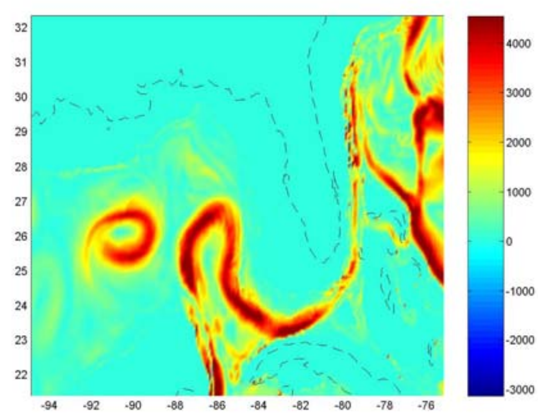

Figure 1. Heat Index visualization.

Measurements done to-date (e.g. [14] for the Pacific Ocean, [15] for the Atlantic) have suggested that the mesoscale eddies and mesoscale features play a strong role in carrying heat poleward. MICOM is one of a few suite of models, where the resolution of the numerical experiments is high enough to resolve the mesoscale eddies. Hence a question alluded to before arises, i.e, to what spatial extent must we resolve the features to get an accurate description of the poleward heat flux in individual isopycnal layers? In addition, how can the physical metric of Poleward heat flux and Eastward heat flux be used to visualize the ocean data better? The latter question was answered in our earlier paper [2].

Poleward and Eastward Heat Flux

The eddy detection procedure is applied on the heat index plots, the visualization metric of the heat flux, that we presented in [2]. We provide some details here as the visualization of the heat flux has been considerably improved since the publication of the paper.

In accordance with the usual oceanographic notation, we take x to be the Eastward and y to be the Northward direction. Poleward heat flux in an isopycnal layer of thickness dp(x,y,l)can be defined as

$$P(y,l) = \int_{Xw}^{Xe} \rho C_P v(x,y,l) T(x,y,l) dp(x,y,l) dx$$

where, x_w is the western boundary of the Ocean basin (the American continent for our North Atlantic simulations), x_E is the eastern boundary of the ocean basin, ρ is the density of the seawater, $\boldsymbol{C_p}$ is the specific heat, $\boldsymbol{v}$ is the meridional velocity component (in the Northward direction – positive values, in the Southward direction - negative values), and $\boldsymbol{T}$ the temperature at points $\boldsymbol{(x,y)}$ for layer $\boldsymbol{l}$. Based on this we defined a new metric called *heat index* as follows:

$$heat\_index(i,j,l) = \frac{v(i,j,l) * t(i,j,l) * dp(i,j,l)}{P(i,l)}$$

We refer the reader to [2] for complete details on the derivation of the *heat index*. Figure 1. shows an example of the *heat index* visualization.

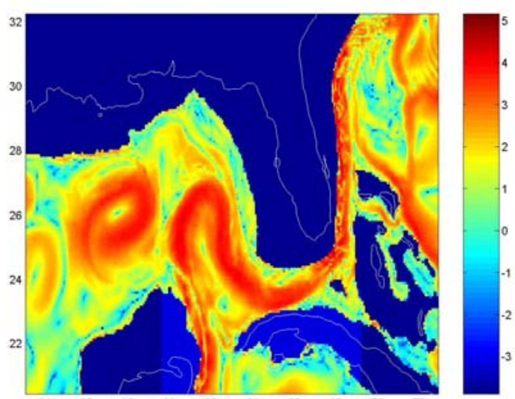

Figure 2. Heat Index visualization in log scale.

Upon further investigation we discovered that the magnitude values at different points in the ocean layer had large magnitude variation (to the factor of 10 thousand). However, over 90% of the values lay on a very small region of this spectrum. A linear pseudocolor plot on the velocity magnitudes alone did not provide much information about the variation of velocities over a given region. A logarithmic pseudocolor plot of the magnitudes shows distinct color contrasts. Eddies, being a feature with a distinct velocity profile, became conspicuous in log scale.

Figure 1. shows a region of the Gulf of Mexico displayed using pseudocolored velocity magnitudes and Figure 2. shows the same on a logarithmic scale. The eddy detection methods described below are applied on the log-scale heat index images.

5. Methodology

The detection of eddies relied largely on direction information of the ocean currents. From the values of eastward and northward flux, the direction of the current at any given location is easily computable. If we were to examine the structure of an eddy in terms of only the direction of currents in the region we would see a very unique pattern, unlikely to be observed in regions of the ocean where eddies are not present.

Shown in Figure 3. are two plots of eddy regions observed in MICOM.

Our first goal was to develop a technique that would automatically scan a layer of the ocean to locate such patterns. We developed a structural element built on directional information to achieve this. Consider a large circle drawn from the center of an eddy. If a comparison were to be made with the direction o f the tangent at any

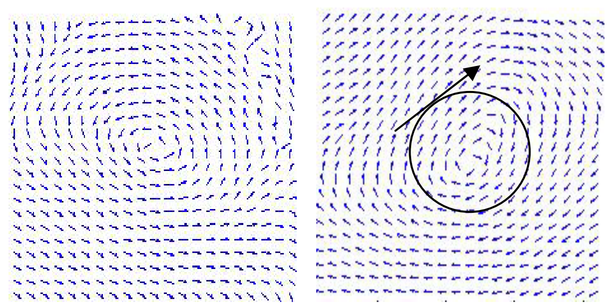

Figure 3. Observer flow fields of eddies.

point on the imaginary circle, and the direction of the current at that particular point, we observed, the values of the angles were very close to each other, with an error of say *e*. It was observed that irrespective of the shape of the eddy, if this circle was chosen to be drawn close to the center, the values of *e* at points on that circle would be quite low. This motivated building a structuring element to search for centers of eddies by examining a neighborhood of 5x5 grid points to determine how likely a center of an eddy would be present in that region. A synthetic eddy structure is shown in Figure 4a.

This structuring element is in fact a numeric stencil of a circular clockwise eddy with the center of the eddy placed at the center of the matrix (shown in Figure 4b). The numbers around the center represent the direction of current (in degrees) of that location. A similar structuring element was developed for counter clockwise eddies.

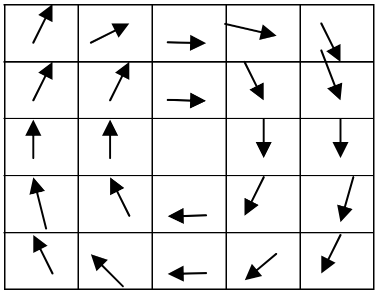

Figure 4a. Synthetic eddy structure.

45	26	0	333	315
63	45	0	315	296
90	90		270	270
116	135	180	225	243
135	153	180	206	225

Figure 4b – Eddy structure and Structuring Element.

Actual eddies have currents flowing in similar directions, but they are not perfectly circular. The angles of eddies observed in the data however, were close in numbers to those of a perfectly circular eddy, in the central region of the eddy. The structuring element was used as the pattern to look for eddies in the ocean layer. Error measurements from these 25 values were used to determine whether a point in the ocean was likely to be a center of an eddy. The eddy detection procedure was executed on several layers for many days of data and highly satisfactory results were obtained (verified manually and numerically). Once the center of an eddy was known, an examination of the velocity vector fields around its vicinity was made using stream plots. Multiple tracers were placed in this neighborhood and their trajectory of these tracers in the velocity vector field over time were simulated and plotted, directed by the velocity field available in MICOM. For points where velocity was not available, interpolation was used. The plots thus generated in the vector field provides confirmation that the region under consideration was actually those of eddies and also indicated how far the eddy extended within the isopycnal layer.

Another visualization technique that was used to enhance the understanding of the eddy structure temporally and spatially was the 3D cone plots. This visualization plots velocity vectors as cones. The tips of the cones are cues to the direction of flow at any given point on the ocean. Cones are colored based on the isopycnic layers to which they belong. The size of the cone gives an indication of the magnitude of the velocities. Animations made using coneplots give a 3D look at the fluid dynamics of the eddy.

Unlike the stream plots, which help us visualize the ocean layers for one particular day, 3D coneplots created using the temporal data help us visualize the variability of eddy structure over weeks. The cone plot shown below is for day 27, layer 4, 6 and 8.

6. Results

Spatial Tracking - The clock-wise and counter-clockwise structuring elements were used to search for eddy centers for every layer of the ocean, for several days. Tracers were placed on three layers of the ocean, where the eddy showed significant activity. The search for activity was done using a bisection method, which helped determine how far the eddy extended spatially. Layers 1, 2 and 3 were not considered, they being surface layers and suffer from atmospheric effects. Figure 5. shows an eddy being tracked spatially**.** Figure 6. shows the cone plot of another eddy, indicating the direction and magnitude of the heat index.

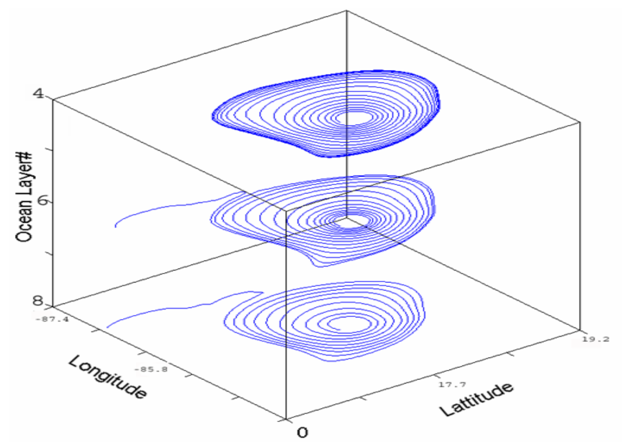

Figure 5. Eddy tracking – spatial. Day 33.

Measurements can be done on the size of the eddy based on the visualization. Regions of eddies that considerably overlapped each other in two consecutive layers were assumed to be part of the same eddy.

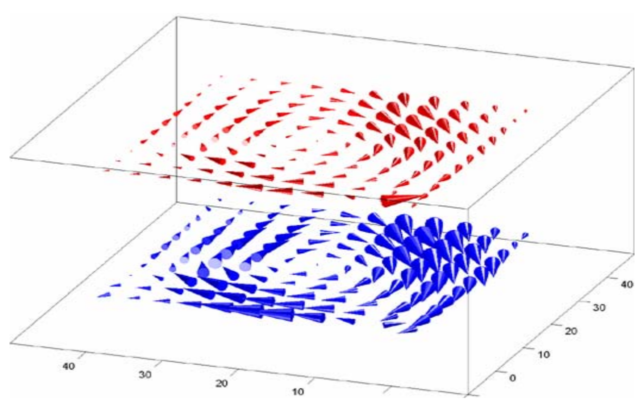

Figure 6. Cone plot indicating direction and magnitude of a spatially tracked eddy.

The spatial structure of the eddy is thus available. Since the data was available to 1/12th of a degree along the longitude and by 1/8th of a degree along latitude the 5x5-structuring element corresponded to 46 kilometers by 70 kilometers near the equator. This would of course vary, depending on specific latitude/longitude points, as 1/12th of degree latitude would cover a shorter distance closer to the poles than they would closer to the equator. In this context one possibility of a false positive would imply that the eddy was smaller than the resolution available in this data set.

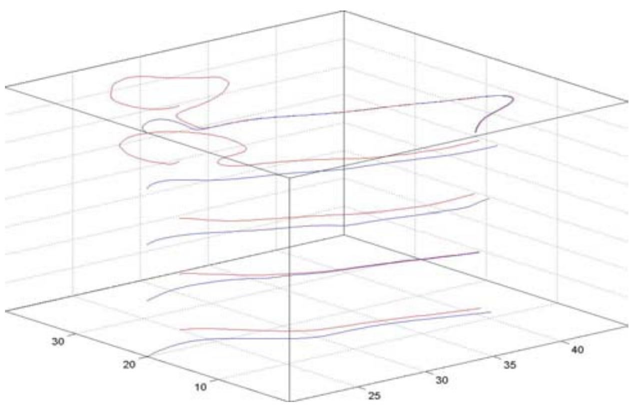

Figure 7. False positive in the eddy detection.

Another possibility is that if the eddy center is larger than the structuring element, when checked against the stream plot, we would detect a diverging streamline. See Figure 7. Using the high-resolution data and a small structuring element also helps us identify non-circular eddies (a limitation of earlier approaches). See Figure 8**.**

Another important inference that can be drawn is the different layers the eddy extends to.

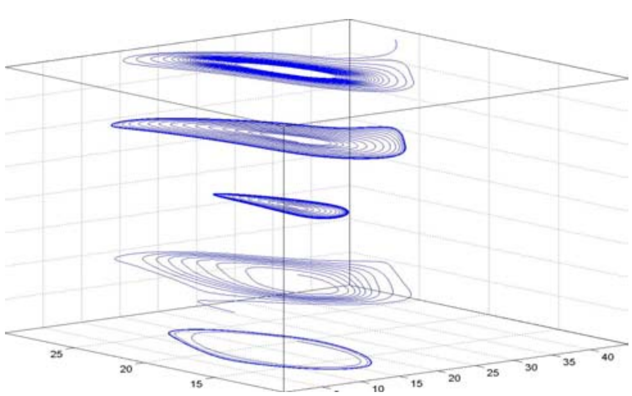

Figure 8. Non-circular Eddy

Temporal Tracking - In consecutive days of data, it was assumed that the eddy center could be found within a small neighborhood of the center detected the previous day (small motion assumption). This assumption was used to track eddies temporally. Tracking an eddy gives us a handle to only the regions of interests in the large temporal and spatial dataset, which is key in limiting our visualizations to eddies alone.

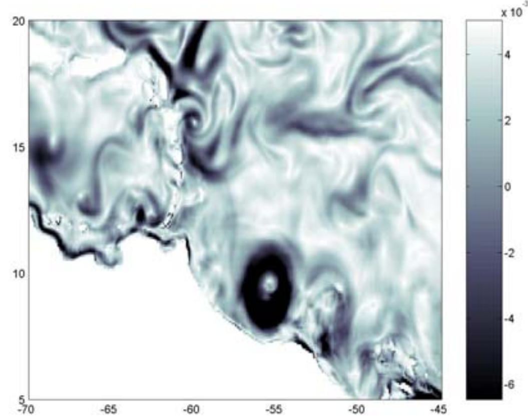

Figure 10a. Eddy tracking. Day 15 layer 5.

Some of the visualizations generated include a pseudo-color look at the velocity magnitudes in the log scale, stream plots in the vicinities of eddy centers both in 2D and 3D, and cone plots of the eddies. Animations were created for the same plots using the available temporal data.

Temporal tracking provides us information on the amount of heat that is being transported by the eddies (yet to be done on this research) but also the direction and magnitude of the eddies. By representing the eddies by their centers (or centroids) we can create a trajectory of the motion of the eddy for further motion analysis. Figures 10a,b,c, show an eddy tracked in the heat index plot.

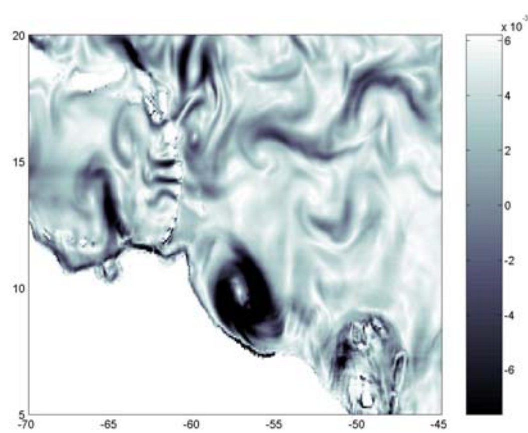

Figure 10b. Eddy tracking. Day 33 layer 5.

7. Summary and Future Work

In this paper we have presented novel methods to detect and track eddies, spatially and temporally. The effectiveness of the methods is demonstrated on a numerical ocean model - MICOM. The strength of this work is in the general approach used and the broad range of mesoscale features that can be detected using these methods. Work is in progress in the areas of quantifying the heat content of the eddies – the cone plot is a useful plot here for visualization. Another area of work, being pursued, is in the detection of other features such as jets and currents.

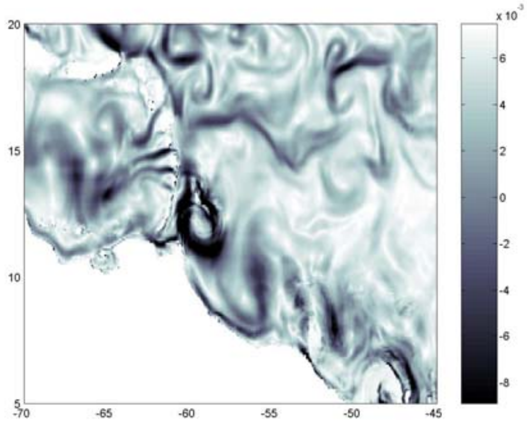

Figure 10c. Eddy tracking. Day 57 layer 5.

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AN ARCHITECTURE FOR VISION-BASED HUMAN-COMPUTER INTERACTION

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ABSTRACT
Computer-vision as a mode of interaction with technical systems has found increasing interest in the past few years. In many of the proposed case studies and applications, the user's current pose is observed by the computer using cameras, and the computer's reaction is displayed to the user who changes the pose accordingly in order to reach a desired goal of interaction. A particular problem with many applications is that the constraints on the environment of interaction should be kept low, in particular concerning illumination, with the consequence that a reliable behavior of the system is hard to achieve by straightforward techniques. We present an architecture which uses time and space coherence, knowledge about key poses of interaction, and feed-back between different levels of the process of recognition, in order to eliminate errors caused by the natural environment. Furthermore, we report on experiences with its application.

KEY WORDS
Computer vision, human computer interaction, gesture recognition, coherence analysis, parameter control, system architecture

1 Introduction

Computer-vision as a tool of interaction with computer-based applications has found tremendously increasing interest in the past few years [6]. A typical computer-vision-based interface [3] is shown in Figure 1. In this scenario, cameras observe a user in an interaction space in front of a display. The display presents the application being subject of interaction. It provides a feedback to the input performed by poses of the user's body. Often, the computer-vision input is just one of several channels on interaction which is, for instance, complemented by speech input.

Typical examples of vision-based interaction are hand gesture input replacing the classical mouse input, cursor control on a screen by pointing with the arm, head tracking for control of the projection of a three-dimensional scene on a screen, or control of a virtual actor or an avatar in a 3d virtual environment on screen.

The challenge for computer-vision is that interaction should take place in natural environments with users "as they are". Particular troubles are varying illumination, dynamic objects like other people besides the user, and varying clothing of the user. In many cases it is possibly to impose constraints on the environment which are canonical and still acceptable to the user, and which allow to achieve sufficiently reliable recognition. The goal, however, is minimization of those constraints. On the other hand, a favorable aspect is that the user can compensate errors caused by imperfect recognition if correction is intuitive. For example, when moving a cursor in a desired region on a screen by pointing by the arm it might happen that the pointing direction and the location of the cursor do not match perfectly. Then the user's reaction might be to move the cursor to the goal by moving the arm elsewhere. In this case it is important that the direction of arm movement causes a movement of the cursor in approximately the same direction.

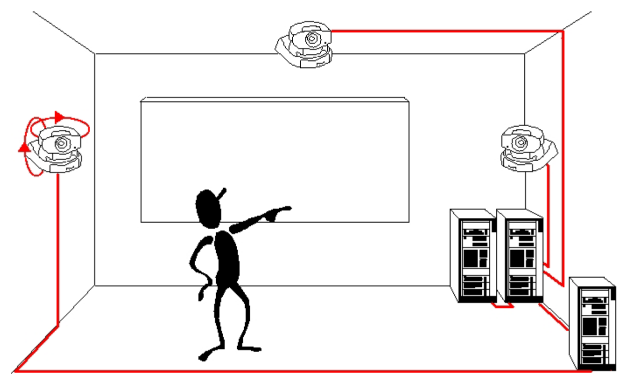

Figure 1. A typical computer-vision-based user interface. The user is observed by cameras and gets feedback from an application on a projection wall.

Another aspect related to this observation is that the required precision often is low compared e.g. to tasks of reconstruction. Less precision can increase the number of possibilities of coping with the effects of the natural environments.

The purpose of this paper is to present a system architecture which takes into consideration the particular requirements of a vision-based user interface of the sort outlined at the beginning.

1.1 Related work

The survey on vision-based human motion capturing by Moeslund [6] gives on one hand a quite comprehensive