Using Wavelet Transformation to Support an Efficient and Adaptive Image Data Handling within a Mobile Environment

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Abstract:
This paper describes our work of using Wavelet Transformation to compress and encode images in order to appropriately support image data handling in mobile systems. The paper at first introduces the motivation and our basic idea of supporting the efficiency and adaptivity at the representation level. In Section 2, the identified requirements on the coding schemata are given which guide the selection of an appropriate transformation method in the image coding schemata. In Section 3, Wavelet Transformation and its advantages for image handling are discussed. The prototype of an adaptive image service is presented in Section 4. In this section, it will also be discussed how various levels of adaptivities can be achieved. Finally, conclusion is made based on the comparison with related works.

1 Introduction

Mobile Computing opens a new era of the information society by introducing a new dimension of mobility to computer applications. Users of mobile computer will be rid of location constraints. In a foreseeable future, a substantial number of users will be equipped with various mobile devices such as Notebooks, PDAs (Personal Digital Assistants) , etc. With these mobile devices, information can be accessed anywhere and at any time [Zha96].
One of the most challenging issues in realizing such a vision is how to provide an Multimedia Data Handling (MDH) that is both efficient and adaptive. Mobile MDH should be adaptive to the available computation resources, the communication resources, the media to access, and the compromise preferences of a mobile client, etc. The adaptivity is needed since current technologies are still subject to some limitations[EFK95] such as very narrow bandwidths of wireless communication networks, limited resources of mobile devices, etc. When the bandwidth is below a certain threshold, a mobile service should be capable of degradating medium quality to remedy the lack of bandwidth. Diversity of mobile devices and wireless communication networks inherently requires a "configurable" or an adaptive MDH.
The technical limitations of mobile computing's technologies imply and necessitate fine grained medium–specific solutions. We have to take the distinctive characteristics of

various media into consideration when developing solutions. Our basic idea is to begin with media coding schemata, because medium–specific properties have to be considered in medium representation, and the adaptivity at the representation level is the most efficient adaptivity. For images, transformation methods come to the fore, as image transformation is the first step which decides the characteristics of the final representation. During the transformation process, an image is converted into another representation in which pixels are decorrelated, and thus are convenient for analysis and quantization. As we shall discuss later, Wavelet Transformation (WT) proves to be a good transformation method for image coding schemata. This work explores the possibility of using WT to achieve an efficient and adaptive image data handling.
The contribution of this work is that it has for the first time investigated the applicability and usefulness of WT for mobile MDH. The developed WT based image coding schema illustrated that WT can also be successfully applied in a totally new emerging field – mobile computing. To our knowledge, there is no other similar effort has ever been made.

2 Requirements on Medium Coding Schemata

Medium coding schemata which support both efficiency and adaptivity should fulfill the following requirements [Zha]:

Data reduction: to reduce requirement on communication bandwidth. and thus to enhance performance and to reduce cost.

Simple computation complexity: so that the compression and decompression process can be performed within relatively short time, and thus, the entire MDAT process has a good performance.

Media quality scalability: low levels of media quality should lead to high performance and cost reduction, i.e., scaled down media should have less data volume, and allow media reconstruction possibly with a lower quality. Media quality scalability is very medium–specific. For visual media, spatial scalability is an important form of media quality scalability.

Partial decodability: partial media content can be reconstructed with partial coded media data. This saves both computation and communication overhead.

Configurability of computation overhead: configurable in computation complexity corresponding to different quality requirements.

Scalability of communication bandwidth requirement: requirement on communication bandwidth can be scaled down or up to adjust to the network used.

Each requirement given above supports the efficiency and adaptivity of MDH in one way or another. For instance, if the image resolution is scalable, then a subsampling

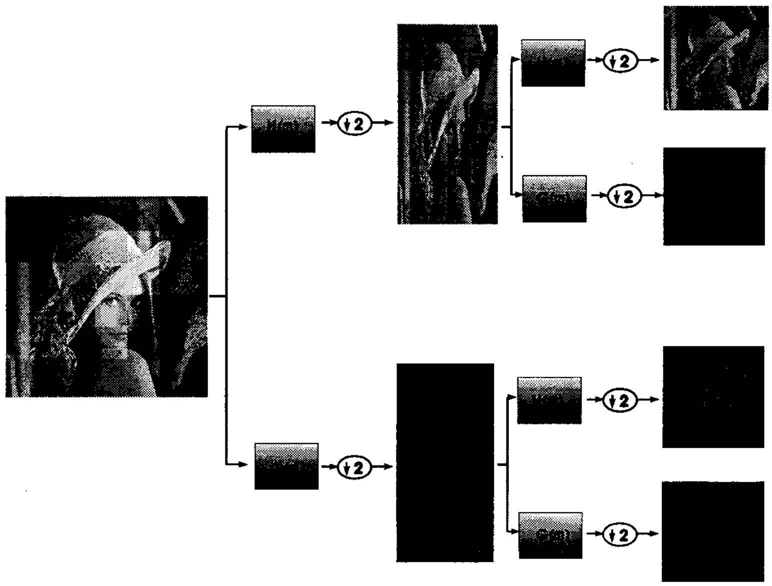

Figure 1: Overview of the efficient Mallat algorithm for image decomposition. An image is transformed into four parts: a subsampled approximation of the original image, and three parts of detail information (differences in horizontal, vertical, and diagonal directions).

operation may not be needed when a PDA accesses a large image. Partial decodability allows a quick responsiveness and region of interest. Configurability of computation and communication overhead accommodates the diversity of mobile devices and wireless networks. Again, for example, if a high end MDT such as a multimedia notebook (whose computation capacity is good) accesses an image service via a narrow bandwidth communication link such as LEOS, then wavelet base Daubechies with high tap such as 12 can be used whose computation overhead for transformation and de–transformation (thus coding and decoding) is high, but allows reconstruction of an image with a relatively good quality although the compression rate is high (thus, less communication overhead). When a low end MDT such as a PDA (whose computation capacity is limited) accesses an image service via a good communication link such as ISDN in a hotel, then the Haar wavelet can be used whose computation overhead is low, and allows good image reconstruction because the compression rate is not very high.
Reviewing the established coding schema for still images, we can see that these requirements are hardly taken into consideration, or not at all. For instance, one of the most popular schemata GIF does not support any scalability in image resolution. JPEG is also limited in this regard, for instance, its baseline (the most popular mode of JPEG which is often regarded as the single mode that JPEG supports) does not support scalability in image resolution. An image coded with JPEG baseline mode has to be converted to hierarchical JPEG coding to support this. Furthermore, the Discrete Cosine Transformation (DCT) is the single transformation available for lossy modes within JPEG. Therefore, the computation overhead is not configurable.

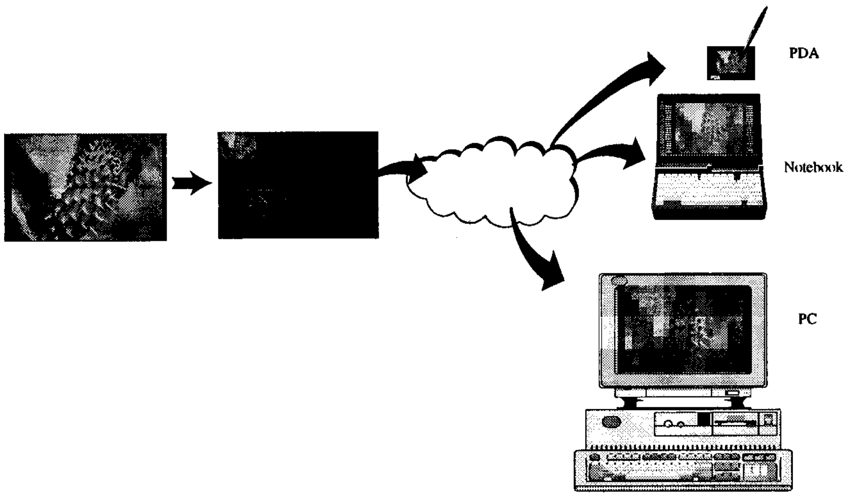

Figure 2: Multi–resolution/levels–of–detail and Region–of–interest support by the means of a WT–based method. The left image is the original image. The image next to the original image is wavelet transformed. Images of different resolutions can be generated from the same transformed image.

3 Wavelet Transformation for Image Data Handling

The WT provides a good means of multi–resolution data decomposition and analysis, and thus gives a multiple view of the signal (image in our context) that is located both in time/space and in frequency [Chu92] [Gro94]. Wavelet basis functions are self–similar and can be derived only by scaling and translating of a prototype.
The WT can be expressed as:

$$WT(a,b) =< f|\psi^{a,b} >= \int_{-\infty}^{\infty} f(x)\psi_{a,b}(x)dx$$

where $f(x)$ is the signal to be transformed, and $\psi_{a,b}$ is the so–called *mother wavelet function* which stands for a set of wavelet bases. Any wavelet base from this set can be used to perform a transformation. Well–known wavelet bases include the Haar wavelet, the Daubechies or the B–spline.
The advantages of the WT include: at first, the WT enables a multiple view of an image. Thus, a wavelet transformed image can be well scaled down in image resolution. Mallat [S.G89] proposed an efficient algorithm for image transformation with a wavelet base (cf. Figure 1). With a wavelet transformed image, a service can deliver images with different levels of resolutions by controlling the image data volume to be transferred. This way, a service can well adapt to various sizes of MDT displays, or enable a compromise between performance, cost and quality (cf. Figure 2). WT based coding is in essence a hierarchical coding. Thus, progressive refinement and previewing can be easily supported.
The WT has a set of wavelet bases available from which an appropriate wavelet base can be chosen according to the actual MDT and the state of the wireless communication link. The computation complexity of the WT is $o(n)$.

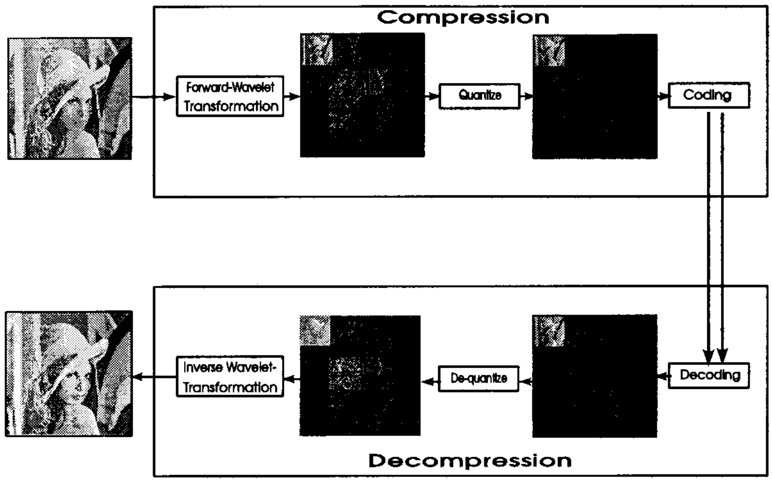

Figure 3: Overview of the WT–based compression and coding algorithm.

Another important advantage is that the WT is perfectly local in time (spatial location for image), while the DCT shows only direction orientation in time, i.e., very weak in spatial localization. Several benefits result from this advantage. Firstly, higher compression rates can be achieved because a further data reduction can be gained by deleting correlation in time as well as in frequency; Secondly, the WT is also suitable for images that contain sharp edges and other discontinuities, because the discontinuities are located perfectly in the corresponding region in every filter bandpass. Thirdly, the WT supports efficient partial decoding. For instance, if an image has been wavelet transformed once (i.e., low fill bandpass is not further transformed) with the Haar wavelet, then only four pixels from the transformed image are needed to reconstruct an original pixel. Finally, the WT supports regional level–of–detail control, i.e., allowing different regions in an image to have different level–of–details (or different resolutions in different regions). This can be made by deleting some detail information contained in high bandpasses, or by enhancing partial pixels. Applications include RoI visualization and image encryption used in electronic publication (cf. Figure 2).

Figure 3 gives an overview of a WT based compression/coding method developed in ZGDV. Similar to JPEG, this method is a hybrid method. It uses RLE and Huffmann entropy coding methods to encode the quantized pixel values. A set of wavelet bases are implemented including the Haar, Daubechies 4, 6, 8, 10,...20, Coiflet 12, 18, and linear B–Spline, etc. These bases can be switched according to the actual situation. Figure 4 shows the test results of computation overhead for image reconstruction with different wavelet bases which are relative to the test image and the test machine computation capacity.

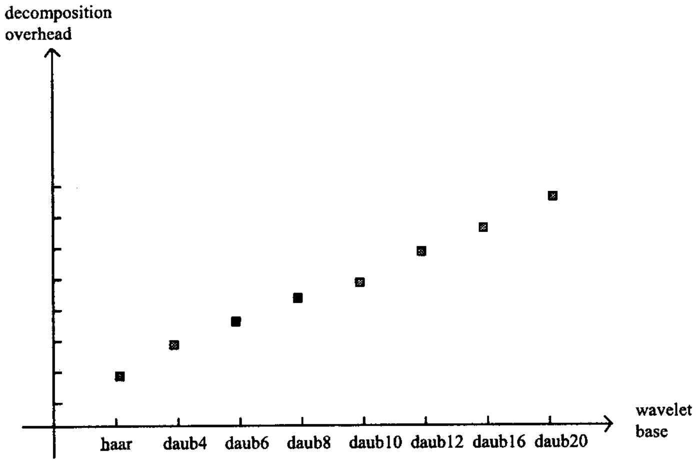

Figure 4: Test results of image reconstruction computation overhead with different wavelet bases.

4 Validation within a Prototype of an Adaptive Image Service

An adaptive image service has been implemented in the system Anna — an Agent based Mobile Information System. The most important reason for using the agent technology in the prototype is that the adaptivity of MDH implies an "intelligent" scheduling component in the service which is adequate to be built up within an agent. Scheduling component has been realized using rule–mechanism.
The architecture of the system Anna is illustrated in Figure 5, while the graphical user interface of the client is shown in Figure 6. The server agent is the single access point of the server. All user requests will be received, parsed, dispatched (if a request should be carried out by another agent) and carried out by it. The server agent uses a session manager, task scheduler and image handler to carry out its following responsibilities:

session management: is responsible of managing task ID and session ID, and resuming an interrupted session with a minimal cost (e.g., through preventing re–transferring data for instance).

task scheduling: MDH adaptation is realized here through evaluating rules. When the scheduler receives a task specification, it parses the parameters, and supplements unspecified parameters. If there is a collision in the specification, it makes a compromise if it is mandated to do so.

image handling: a task is handled according to the task schedule given by the task scheduler. At present, the handling functionalities include image clipping, RoI, previewing, compression, various image formats, and progressive refinement, etc.

Rules are established to realize an adaptation during run–time. The following are some examples of rules used:

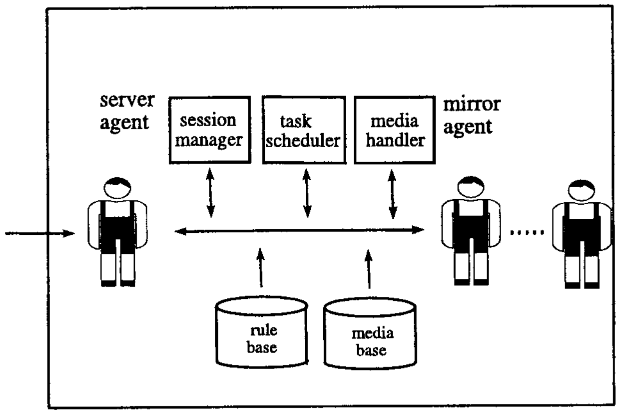

Figure 5: Architecture of the server in Anna.

r^1 : `regionOfInterest` $\dashrightarrow$ `fRoIFiltering`
r^2 : `(remote.width > (widthInterval*(1 + toleranceDegree))`
`|| (remote.Height > (heightInterval*(1 +`
`toleranceDegree)))` $\dashrightarrow$ `fSubsampling`
r^3 : `(format == GIF)` $\dashrightarrow$ `fGIFgenerating`

where r^1 means that if the parameter `regionOfInterest` is specified, a region–of––interest filtering operation `fRoIFiltering` should be performed. r^2 means that if the accessed image has a larger width or height than required (including tolerance degree), then a sub–sampling operation `fSubsampling` should be made. r^3 means that if the parameter format is specified as GIF, then the `GIF` format generation operation `fGIFgenerating` will be carried out.
The following is an example of a task for getting an image:

```
getImage (imageReference = "face.gif", format =
[GIF, TIFF], width = [300,350], length = [200,250],
regionOfInterest = (default, 3), tolerenceDegree =
(width, height, 5))
```

This specification means that an image stream should have a syntax/semantic of either the format `GIF` or `TIFF`. The image width lies in between `300` and `350` pixel, and the height in between `200` and `250` pixel. Region–of–interest is required if it is supported by the media provider.
A very important point of our design is, task parameters are allowed to be specified in the form of an interval, an option list or in a conditional form. This enables an image service to have more room for adaptation. Different levels of adaptation are possible. When an task specification is given without any of its parameters being assigned a value, then the service can perform adaptation up to 100%. If all the parameters of a specification are precisely specified, and no collision arises during the task scheduling, then the service just does precisely what is demanded, thus has a adaptation of 0%. Between these two extremes, where when some parameters are not specified, or there is a certain collision

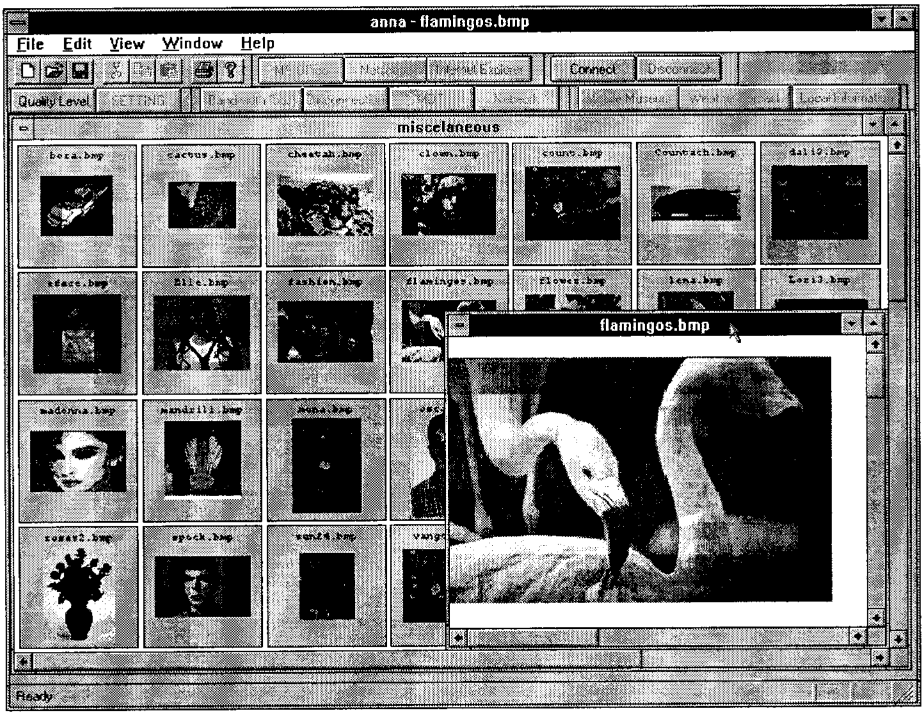

Figure 6: Interface of the prototype system Anna.

in specification, or parameters are specified with intervals, option lists, or in a condition form, the service has a certain level of adaptation.
In the current implementation, the server runs on a Unix workstation which is connected to a public switch telephone network via a normal modem. The MDT is a notebook running Windows NT which is connected to a D1 telephone via a PCMCIA modem card. D1 is a GSM wireless network operated by TeMobil in Germany. TCP/IP is used as the high level API for data communication. Internetworking between internet and GSM is provided by D1.

5 Related Works and Conclusion

Adaptivity plays more important roles in mobile systems than in desktop systems. Different research groups have realized the importance of adaptivity in mobile systems, and provide various innovative solutions from various perspectives. Two representative related works are briefly compared in the following to highlight the contribution of this work:

Code and Odyssey: have been carried out in Carnegie Mellon University concentrating on adaptation strategies for mobile information access. Two main research projects of this group are Cada [SKM+93] which supports a cash–based application–transparent adaptation, and the Odyssey [NPS95] which supports application––aware adaptation APIs. One of the interesting results of their work is a definition

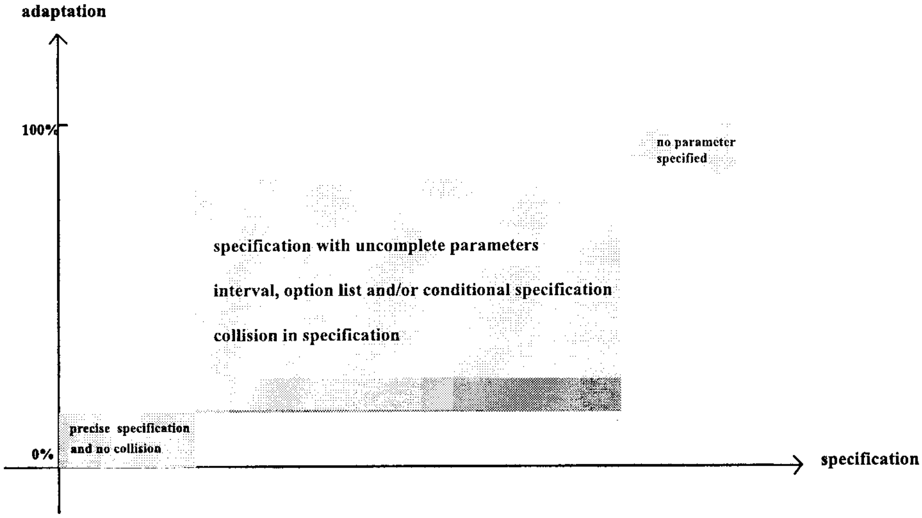

Figure 7: Different levels of MDH adaptation.

of a taxonomy of various adaptation strategies. they defined a range of adaptation strategies from *Laissez–faire*, *application–aware*, to *application–transparent*. According to this taxonomy, our adaptation strategy is *application–aware*.

MOST: The project MOST has been carried out by Lancaster University in the UK [NDA] The objective of this project is to develop a kind of *adaptive* or *reactive* service that can work well in a heterogeneous, dynamically changing (especially in terms of QoS) mobile environment. The approach they used is to extend ANSAware with a so–called *explicit binding*. With an explicit binding, a mobile client is allowed to specify or monitor a set of different QoS parameters associated with the binding. Such a binding can be regarded as a channel whose current state can be monitored and used for the decision of an adaptation.

Clearly, both works deal with the issues at a higher level than the level of multimedia objects (i.e., at the level of data objects where multimedia features are still transparent). Therefore, adaptivity is usually treated without taking distinctive features of various media into consideration. The benefit of this strategy is that the achieved solutions are more general. However, we argue that fine grained medium–specific solutions are needed because mobile MDH is subject to the technical limitations of mobile computing's technologies. This work takes the medium–specific features into consideration right from the beginning, and tries to support the adaptivity in the medium representation. At present, we have only investigated image data handling. The basic idea should be also applicable to other media.
Now we can draw the following conclusion: efficient and adaptive MDH is needed for mobile systems for which distinctive features of various media should be taken into consideration. The adaptivity is at best supported in the medium representation, as the adaptivity at representation level is the most efficient adaptivity. WT is very suitable to

be used to develop image coding schema that supports adaptivity. Different levels of adaptations can be realized during the task scheduling process.

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