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Illustrated Ultrasound for Multimodal Data Interpretation of Liver Examinations

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Abstract

Traditional visualization of real-time 2D ultrasound data is difficult to interpret, even for experienced medical personnel. To make the interpretation during the education phase easier, we enhance the visualization during liver examinations with an abstracted depiction of relevant anatomical structures, here denoted as illustrated ultrasound. The specifics of enhancing structures are available through an interactively co-registered computed tomography, which has been enhanced by semantic information. To assist the orientation in the liver, we partition the liver into Couinaud segments. They are defined in a rapid segmentation process based on linked 2D slice views and 3D exploded views. The semantics are interactively related from the co-registered modality to the real-time ultrasound via co-registration. During the illustrated ultrasound examination training we provide visual enhancements that depict which liver segments are intersected by the ultrasound slice.

1. Introduction

Ultrasonography (US) is a potent clinical tool. As a diagnostic modality, US has the advantage of being noninvasive with no or little patient discomfort, providing high safety with neither contraindications nor radiation exposure [BHZ*00]. It is also a practical tool for the clinician being inexpensive, portable, easy to repeat, and independent of all other personnel but the examiner. The most widely used ultrasound mode is the B-Mode that measures the acoustic echo of the tissue. In comparison to other imaging tools as computer tomography (CT) and magnetic resonance imaging (MRI) that provide very good spatial resolution, US offers a high temporal resolution, which makes US an invaluable tool for examinations where both anatomic and dynamic information is important [ØGG05]. This is particularly important in interventional procedures where the examiner for reasons of accuracy and safety would like to be able to observe the culprit lesion and its surroundings at all times during a procedure.

Ultrasound imaging does, however, offer some difficulties regarding retrieval and interpretation of image information. US is heavily attenuated by air and bone and to some degree by fatty tissue [ØGG05]. This makes imaging of intra-abdominal structures difficult in obese individuals and certain features may hide behind gas in the gastrointestinal tract. Furthermore, the interpretation of US images is based on a thorough understanding of anatomic relations and the expert ability to recognize these relations in a noisy image slice. As the image uptake is done by free hand operation and interpretation is done in real time, acquisition is very dependent on the examiner. Consequently, examiners have a long learning curve in interpreting ultrasound images [ØNG07].

A common case is the US examination of the liver. Examiners investigate overall liver tissue characteristics, or look for structures such as cysts or tumors that might require a biopsy. During the examination it is important to localize important structures correctly and describe how they relate to the rest of the liver, especially to the blood vessel tree. A frequently used scheme for partitioning the liver is the

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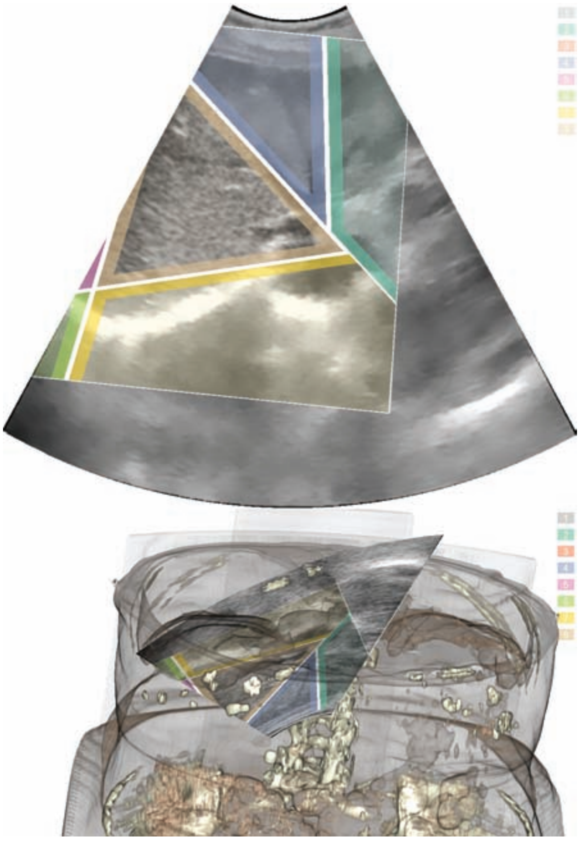


Figure 1: *Interactive illustrated ultrasound showing a Couinaud segmentation on top of the US scan (top) and embedding of the US scan into a co-registered CT volume (bottom). The coloring in the illustrated ultrasound depicts the membership of the respective cross-sectional area to the Couinaud segments (1-8) [Cou57].*

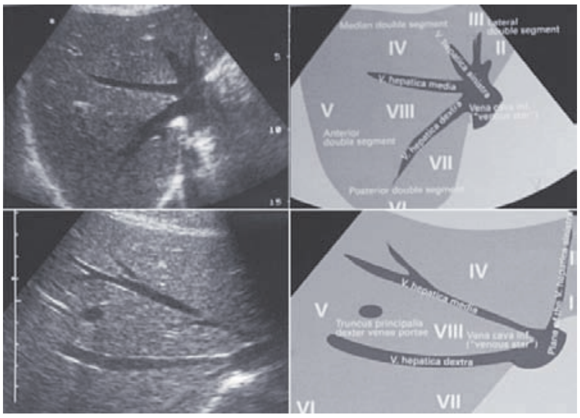


Figure 2: *Navigational posters: Characteristic ultrasound views on* Vena Cava *and* Vena Hepatica*, coupled with interpreted simplified illustrations.*

Couinaud segmentation [Cou57]. This segmentation divides the liver parenchyma into eight different segments based on planes that are aligned to main vein structures, i.e., the Hepatic Veins (Right, Middle, and Left) and the Portal Vein.

To assist the interpretation of ultrasound images during the liver examination, examination rooms in hospitals often are equipped with poster illustrations showing typical ultrasound views in a simplified fashion, combined with textual description of the shown anatomy, often also with linked 3D anatomy views or other semantic information. Examiners are using these posters for orientation, especially in an early stage of their clinical experience (see Figure 2). Even experienced medical personnel is occasionally taking advantage of these navigational posters for understanding spatial relationships.

A trend in modern interventional procedures is to use information as obtained from CT or MRI modalities as a guide during a freehand US examination. This can be achieved by co-registering the CT or MRI with magnetically tracked 2D US scan. The CT or MRI modalities offer clear anatomical detail in areas where the US images for some reason have reduced quality while the US offer a live view of the area of interest. In this way the examiner can exploit the strengths of both modalities. The co-registration is usually not voxel-accurate, but it helps the mental registration of modalities by the examiner. Although co-registration of these modalities is increasingly available in new commercial software packages, there are only few visualization techniques that make explicit use of this rich data combination.

And this is exactly where we place our approach to enable patient-specific enhancement of US examinations in the spirit of the above mentioned navigational posters. A comparison of our technique that embeds the enhanced US image into the CT volume context and a poster example from one of our examination rooms is depicted in Figures 1 and 2. Figure 1 illustrates how the idea of navigational posters can be integrated into a live examination procedure. Instead of having a set of standardized views, the examiner is provided with patient-specific liver partitioning anytime and anywhere during the examination. This can be realized on demand by enabling the overlays for particular time only or for the entire examination. Such enhancement provides clear orientation in examined organ especially for personnel in learning phase of the liver examination procedure.

2. Related Work

Research related to advanced ultrasound visualization has been mainly focusing on the development of techniques for noise-free image synthesis of a three-dimensional visualization. The direct volume rendering of 3D ultrasound requires a filtering stage to precede the volume rendering stage [SSG95]. More recent approaches are using probability metrics to evaluate a presence of an interface between tissues [HRH03]. Further on, highly redundant information from the 3D US volume overlap of consecutive scans can be exploited to improve the rendering by preserving the temporal coherence [PHHH05].

The 2D ultrasound rendering has been in the past combined with augmented reality hardware to blend the ultrasound with real environment. The ultrasound images have been displayed in context of the patient's body to depict where particular US image intersects the body [BFO92]. Nowadays, registration techniques are usually based on registration using internal or external markers within the anatomical structures in both US and the pre-interventional modality. In clinical practice mostly non-rigid registrations are used [LMPT07, NFN07].

Commonly the visualization of coregistered US and CT (or MRI or PET) is realized through separate linked views where each modality is displayed separately and there are no special markups added to relate the two images apart from anatomical structures. Another frequently used visualization of two co-registered modalities is slice-based rendering with fusion of the images using blending. This type of multi-modal integration is very typical for PET/CT visualization for example [KCF05]. The ultrasound slice is often fused in a similar way with MRI for neurosurgical interventions, for example [NHL*03, RHR*03]. To provide better 3D orientation, an integration of 3D CT visualization with 2D interventional ultrasound has been recently proposed for CT-US-guided intervention and biopsy sampling incorporating cut-away views [BHW*07]. Organs and pathologies are given visual prominence according to their relevance in the intervention and their relation to the ultrasound image. All commercially available techniques, such as fused visualization of PET-CT through slice overlays, or linked CT-US slicing, or fused visualization of CT and US using contextual cutaways operate primarily on the data level. They do not aim at transferring higher-level semantics associated with one modality into the visual depiction of the another modality.

In our case of liver examinations, the semantics are the Couinaud segmentation of the liver into eight segments [Cou57]. Despite of the fact that the branching vascular structures in the liver strongly differ from individual to individual, this abstract segmentation principle is frequently used especially in medical communication. The segmentation of the liver is an active research area with many solutions from fully automatic to semi-automatic. Fully automatic techniques usually rely on high-contrast, high-precision CT datasets [SDM*01]. The Hounsfield intensity differences between parenchyma and vessels have to be well differentiated to be able to perform vessel classification since the knowledge about the vessel topology is crucial for automated Couinaud segmentation. Automated techniques can be combined with user-steered solutions [SPP00] in order to

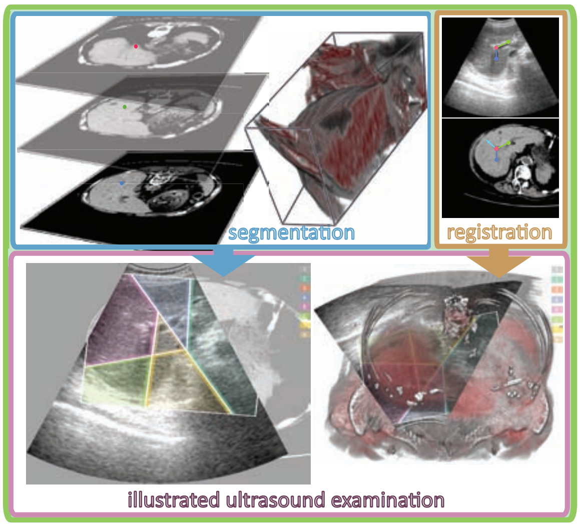


Figure 3: *Liver segments are obtained by the Couinaud segmentation (left). On axial slices three center line points for each vein are specified. Proper intersection can be validated by seeing the vein along the planar cut. Transfer of segmentation to live ultrasound is established by coregistration (right). Corresponding landmarks are depicted by red, green, and blue points. Illustrated ultrasound examination (bottom).*

extract the liver organ from the CT data initially and also to avoid uncontrolled region growing. The segmented liver can be then used for surgery planning and to design a minimal damage strategy for tumor resection [BRS*06], for example. Further information about liver segmentation is provided by Campadelli and Casiraghi [CC07]. In our pipeline we have realized a simple fast segmentation approach that is not very sensitive to the quality of the CT data. Therefore we can use standard abdominal CT scans without contrast enhancement and the patient does not need to take one more (radiating) screening procedure.

3. Illustrated Ultrasound Pipeline

Navigational posters such as those demonstrated in Figure 2 served as the primary inspiration for the here presented approach, denoted as *illustrated ultrasound*. We enhance traditional US imagery by overlaid illustrative visual structures [RE01] that transfer semantic information from a co-registered modality. In our application case, the illustrative ultrasound enhances the live liver examination in a similar way as the navigational posters do by partitioning the US image into Couinaud segments [Cou57].

To enable *live* examinations guided by illustrated ultrasound we assume the existence of an abdominal CT scan. The second assumption is the support of ultrasound probe

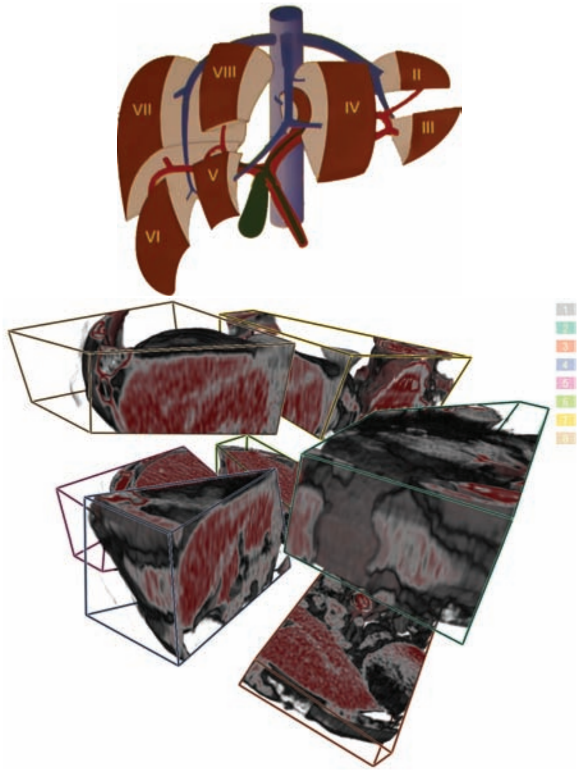


Figure 4: *Comparison between schematic illustration of Couinaud liver segmentation (top) and the resulting partitioning using our segmentation approach utilizing exploded views (bottom). Bounding geometry coloring corresponds to the legend of liver segment numbering.*

tracking, so the position and rotation of the US probe are known for every frame in the sequence. For the application in mind, we aim at an as efficient pre-processing as possible. First, it is necessary to build-up the semantics which are to be visually transfered to the US examination. More specifically, the data from the CT acquisition will serve as a basis for the Couinaud segmentation. The next step is to co-register the patient's spatial position with the CT scan coordinates. There are several approaches available for liver segmentation and registration that can be used in this pipeline.The optimal situation is to fully automate this pre-processing stage.

We have developed a new method for a Couinaud segmentation and use a simple registration approach for the illustrated ultrasound examination. We take special care that the interaction metaphors during preprocessing are (a) not entirely new to the medical personnel, (b) simple enough to soon become routine even for non-computer specialists, and (c) fast so that the preprocessing does take minimal time for experienced users. When pre-processing is completed, the illustrated ultrasound examination can proceed. During the examination the user can enrich the ultrasound, when needed, by additional visual information from the set of overlays to better understand spatial arrangement of structures. The here described illustrated ultrasound pipeline, with lobe segmentation semantics, is shown in Figure 3. We propose an integrated visual computing pipeline from data acquisition to assisted interpretation. Individual steps of this all-in-one solution are discussed in detail in the following sections.

4. A Fast Couinaud Segmentation

The Couinaud segmentation defines the eight liver segments through the definition of four planes that approximately partition the space into the liver lobes [Cou57]. It is based on information of vascular localization and thus particularly useful for the surgeon when planning liver resections. The number of segments a liver tumor covers and the localization of these segments directly affect the surgeonŠs treatment decisions and have profound prognostic importance. A clear visualization of these segments is important not only for the inexperienced ultrasonographer, but also in the communication between the examiner and the surgeon.

The segmentation planes are aligned with the hepatic and portal veins. The plane of the Right Hepatic Vein (RHV) is oriented to contain the centerline of RHV as analogously the planes for the Middle Hepatic Vein (MHV) and the Left Hepatic Vein (LHV). The Portal Vein (PV) defines an additional plane that is almost perpendicular to three Hepatic Vein planes. These planes partition the space into eight half spaces, and into 7 segments (Segment 4 consists of two half spaces, i.e., it is not partitioned by the PV plane). One additional segment, i.e., Segment 1 is defined as the region in close vicinity of Vena Cava and the PV. The schematic liver Couinaud segmentation is illustrated in Figure 4 (top) as also seen in standard medical education materials. A respective partitioning from our approach is depicted in Figure 4 (bottom). The color legend assigns the number to the segment which is enclosed in bounding geometry of the same color.

This simple geometric segmentation can be performed by defining the planes through specifying three points in the liver CT data for each of four partitioning planes. As medical personnel is familiar with the manipulation and processing of CT data using slice-based visualizations, we provide the selection of the plane-defining points in the axial view. Previously defined points remain visible even if they have been defined on different slices. It is very helpful for plane definition to keep track of information about their on-slice location. The point selection to define a partitioning plane and the resulting partitioning is shown in Figure 3.

The Couinaud Segment 1 is located on the posterior surface of the liver adjacent to Segment 4 and is not defined by any of discussed partitioning planes. Segment 1 is easier to discriminate due to its position between caval and portal veins. This is not the case for other lobe segments which

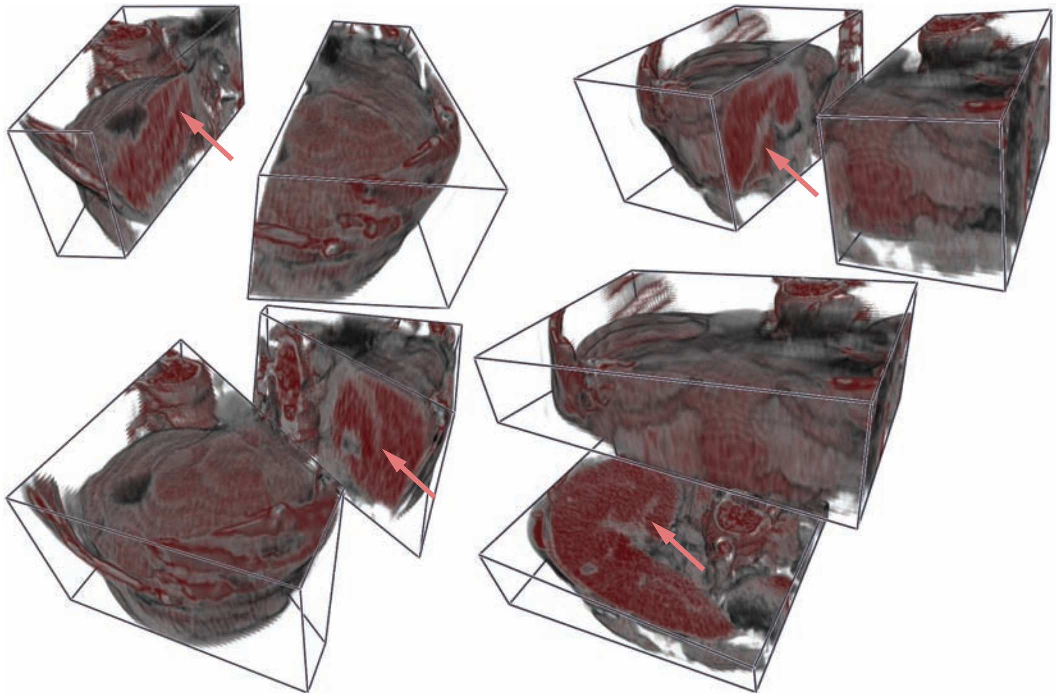


Figure 5: *Validation of the segmentation of the liver into Couinaud segments using exploded views for volume data. The planes are intersecting vascular structures (from top left to bottom right) Right Hepatic Vein (RHV), Middle Hepatic Vein (MHV), Left Hepatic Vein (LHV), and Portal Vein (PV). Arrows are pointing to respective veins.*

apart from the vascular topology are not separated by any boundaries visible in the CT or US images. Segment 1 is of spherical or elliptical shape and we approximate this region during the segmentation by a spherical mask.

Normal clinical datasets usually differ from those datasets that are usually used for demonstration purposes by a limited radiation dose and thus are of lower resolution in the *z*-direction. Many of the available CT datasets, which have been acquired from the patients before the US examination, are standardized abdominal CT scans without additional vessel contrasting. This makes the datasets unsuitable for many fully automatic liver segmentation methods. Vessels become visible for the user only after selecting appropriate window levels and can be of even lower intensity than the parenchyma. Performing the plane placement directly in a 3D view which utilizes semi-transparent volume rendering is extremely difficult in the clinical routine. Semi-transparency in rendering is impractical and a more dense visual representation is needed. On the other hand, defining a plane by point selections on 2D slices requires a validation of the plane placement in 3D, showing the entire structure of the liver. Therefore we utilize the illustrative concept of exploded views [BG06] for validation of proper plane placement in the 3D view. Our segmentation environment consists of two linked views, i.e., a slice view for plane definition and an exploded view for validation. After the specification of three plane points, an explosion of half-spaces as defined by the plane is automatically initiated and both sub-volumes can be inspected for proper plane placement. As the planes have to be placed approximately through the center lines of the corresponding vascular structures (i.e., RHV, MHV, LHV, or PV), these structures have to be visible on both segments that are cut by the defined plane (which then leads to validation). After a plane has been successfully defined, the segmentation can proceed into defining another plane in the 2D slice view. The explosion is collapsed and triggered again when the points for the new partitioning are defined. Although it is possible to include all already defined partitioning planes in the exploded view, we found that approach quite overloaded. Therefore, we always displace only two half spaces, corresponding to current plane definition during validation. The plane placement validation for each vein can be seen in Figure 5. After the definition of the vein-aligned planes, and the spherical region is completed we display the result of the entire segmentation to see how well the segmentation corresponds to the schematic Couinaud segmentation. We can also observe the size of individual segments which varies from patient to patient. We show each segment enclosed by the bounding geometry as defined in the segmentation. The bounding geometry wireframe of each segment is colored to associate each segment to a color legend that defines the number of the individual liver segments as shown in Figure 4.

5. Registration

After the segmentation part of the pipeline has been successfully completed, the CT-US coregistration step is necessary before the live illustrated ultrasound examination is started. The coregistration of ultrasound with a pre-interventional modality is an active research area, where many approaches are nowadays supported by the commercial medical software packages. In our pipeline we have decided to use a simple rigid + scaling (similarity transform) coregistration technique based on selecting and linking internal landmarks that are visible in both modalities. Vascular structures, particularly divisions, on the posterior abdominal wall are generally recommended to serve as internal landmarks as they are stable and easily identified on both modalities. Our approach is based on the idea of identifying three anatomical features visible in both modalities and let the examiner indicate these through placement of points in the data. These two sets of points can then be used to compute a rigid transformation from one modality to the other. Selection of more than three points would allow more precise registration allowing optimization using least-squares fitting [AHB87], for example.

In our particular case, the examiner selects three preferred points in the ultrasound image, where their relative position is defined by a built-in tracking sensor on the ultrasound probe, providing a relative position for each image in the ultrasound sequence. Although it is possible to select features in different ultrasound probe positions and orientations, the preferred approach by the clinical side is to identify interesting regions that are present in a single ultrasound image and perform landmark selection on this relatively static (up to patient's respiration) image. In case of liver coregistration, the vascular structure topology can be used for this purpose, for example a bifurcation of a larger vessel offers suitable landmark points.

After the three spatial points have been defined in the US data, three anatomically corresponding points have to be defined in the CT volume. Two of these are freely selected by the examiner using 2D slicing. The points can be located in different slices. We then require that the third point should be placed so that the three points define a structure geometrically similar to the three corresponding points in the US data. This is due to the similarity transform used by our registration. The requirement constrains the position of the third point to be located on a circle in a plane normal to the vector defined by the two already selected points. To define the final position of the third point, the user is offered on each CT slice two points (in general) which are defined as the intersection of the current slice with the circle. The examiner selects the position of the third point by slicing and choosing one of the offered points. If the circle in the CT data does not intersect the same anatomical point as the third point in the US data, this indicates that the positioning of the other two points might be imprecise, and the selection of points has to be repeated. The selection of landmark points in each modality is depicted in Figure 3, where landmarks in each modality are depicted by red, green, and blue points. The six points now define the spatial relationship between the modalities, and a transformation mapping, i.e. the CT set of points to the ultrasound set, is found by applying the necessary scaling, translation, and rotation. This transformation defines the coregistration, and the link between US and CT is established.

6. Live Illustrated Ultrasound

The ultrasound, CT, and semantics from the pre-processing step, provide a rich set of information which can be effectively combined during the ultrasound examination. The direct visualization is the original ultrasound without any visual enhancements. We do not underestimate this visualization as it delivers most of the examination information. One simple enhancement of the ultrasound, still entirely on the data level, is overlaying US with the CT information in spirit of standard visualization methods for co-registered PET-CT visualization. This is helpful especially for regions that are not visible by ultrasound due to the low acoustic penetration as caused by bone or fat tissue occlusion. The commonly used linked-view and slice-based visualization of coregistered CT and US shows the entire reconstructed CT slice. For better perception we can use the ultrasound *geometry* scanning bounds as a stencil in the CT view to clearly show which part of the CT slice is in the US frustum and which is outside the visible region of the ultrasound. Another possible feature are *multimodal collages*. In our case the spatial coverage of the CT slice is often bigger as compared to the US slice. The multimodal collage consists of two areas: in the area inside US frustum we show the US slice and outside the frustum we show the reconstructed CT slice to increase the anatomical information extent.

The main purpose of this work is visualization with overlaid information about the lobe partitioning semantics intersected by the ultrasound plane. This serves orientation purposes showing which part of the ultrasound image belongs to which liver lobe (approximately). This visual representation overlays the ultrasound information (could be overlaid over CT as well) but should not eliminate or obscure the important information from the examination. Therefore this information should be visible but subtle at the same time. We draw simple lines in the ultrasound plane that are surrounded by a thicker semitransparent region of particular color that corresponds to particular liver lobe in the color legend. The rest of the internal part of the partitioned US image is very subtly toned with color assigned to a given lobe. We have borrowed this technique from cartography where for example the country borders are clearly shown, and at the same

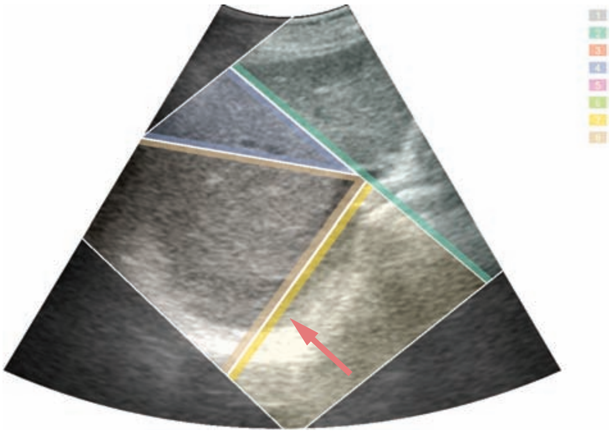


Figure 6: *The illustrated ultrasound technique combines the ultrasound image with the Couinaud segmentation semantics. Lesion location is depicted with arrow.*

time the geographical information is preserved to the maximal extent. The border thickness can be set to convey information about the uncertainty whether or not that particular region strictly belongs to the corresponding lobe or it rather belongs to a transition area due to imperfection in segmentation, tracking, and co-registration stages. In case when the semantics overlay occludes structures of interest, what can be naturally often the case of the veins, illustrated ultrasound can be disabled and enabled again on userŠs request.

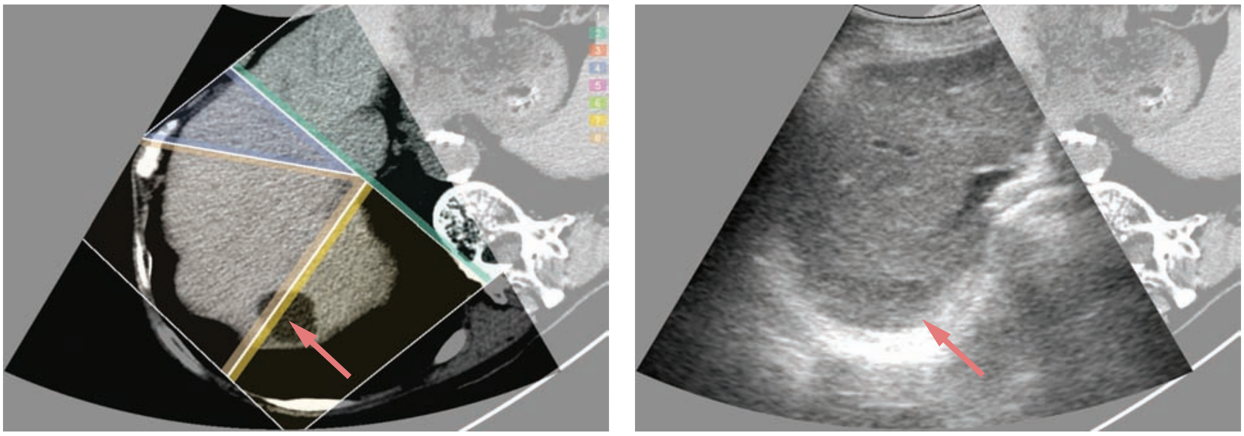
We demonstrate the features of the illustrated ultrasound on the following clinical case. The patient is an 82 years old female with an incidental finding of several lesions in the liver parenchyma after a abdominal CT scan. The lesions seemed cystic in origin and to establish the diagnosis an ultrasound examination of the liver was performed to eventually confirm these findings. Ultrasound data and co-registration was obtained with a Loqic 9 US scanner (GE Medical Technologies, Milwaukee, Wisconsin, USA) using a curved 4 MHz ultrasound probe in combination with a commercially available magnetometer-based position and orientation measurement device (Bird, Ascension Technology, Burlington, Vermont, USA). The image uptakes were stored in RawDicom format together with the tracking information. The CT scan was acquired at a resolution of $512^2 \times 81$ with 1 mm on-slice resolution and slice thickness of 5 mm. Figure 1 shows both co-registered modalities where the US slice enhanced with illustrative ultrasound techniques is embedded in the abdominal CT. The US image shows a cross-section perpendicular to the hepatic veins where all the upper Couinaud segments are visible.

One of the lesions was located at the top of the liver between the Segment 7 and 8. The lesion was clearly visible on the CT scan whereas it was more difficult to see on the US image. For educational purposes our modality will help medical students in locating such a lesion on US. The predefined Couinaud segments tell us in which segments the lesion is located even though the defining vessels cannot be seen in the same section. If a biopsy of a similarly placed lesion was needed it could also be used to guide the physician taking the biopsy using ultrasound, which is the preferred modality for intervention. A cross-section through the lesion is shown in Figures 6 and 7 where we can see Segments 2, 4, 7, and 8. The series of four images in these two Figures demonstrates the different possible visual combinations.

The image in Figure 6 shows the ultrasound image in combination with the Couinaud segmentation. The region of the segmentation is visually emphasized, structures outside the liver boundaries determined by the bounding box specification enclosing the liver are slightly dimmed. The lesion is located on the border between the Segment 7 and 8 close to the high intensity region (diaphragm).

Switching to the CT modality that reconstructs a CT slice co-registered to the US image, allows to clearly see the lesion. The attenuation of X-rays in the CT is much lower in the lesion as compared to the normal liver tissue. This is shown in the image in Figure 7 (a). Moreover as the CT slice contains information outside the US frustum, we consider it as valuable to display that region as well. In contrast to standard linked CT-US views, we indicate the frustum of the US image by giving the regions outside slightly sparser visual representation. This strengthens visual orientation cues as it becomes more clear which part of the CT is actually supposed to be seen by the US. Going one step further we can combine ultrasound and CT modalities in such a way that the US frustum shows the B-mode information from the ultrasound modality and outside this region the reconstructed CT slice is shown to provide more information about the anatomy. Such a CT-US fusion can be seen in image in Figure 7 (b).

The visualization software provided by the vendor does not give the opportunity to access the US slices during the examination, we performed this demonstration of our approach offline, accordingly. The traditional ultrasound examination has been stored as a sequence of images with tracking information that has been imported together with CT to our demonstration environment. The entire pipeline has been implemented as proof-of-concept in the VolumeShop framework [BG05]. The implementation is using graphics hardware acceleration through the OpenGL shading language. The slice-based visualization is using plane intersection tests in shader code to determine the segment partitioning. The overall performance is highly interactive. The highest computational resource consumption has the exploded view where we achieve average framerates of 10 FPS on an Nvidia GeForce 9600 graphics card. The system is, however, under development and it does not yet provide sufficient precision to be utilized in daily clinical routine.



(*a*) (*b*)

Figure 7: *Illustrated ultrasound shows the coregistered reconstruction of the CT slice with the Couinaud segmentation semantics (a) and multimodal collage of ultrasound and CT (b).*

7. Utility for Examination Training

US examinations require a long learning curve. Medical students intuitively understand the abstract anatomical 3D model while reading a fixed CT slice often can be a difficult step. Interpreting freely moving US sections is even harder. The US data has in general low S/N ratio and is dynamic as it captures the acoustic properties of functional processes.

Major training steps can be bridged by the illustrated ultrasound concept. The transition from 3D anatomy understanding via CT reading to US reading is aided by the visualizations which the illustrated ultrasound offers. An US examination trainee performing a liver examination can utilize this when asked to localize specific structures in the liver. If she experiences difficulties in interpretation, she can overlay several different levels of information and learn how they correspond to each other. When using illustrated ultrasound with liver examinations the relation between the US data and CT data, the abstract model of Couinaud segments, and their location in 3D can be shown for any position of the probe. Therefore the understanding of the correspondences between these different representations of liver anatomy can be build-up even without the active presence of experienced examiner.

Another important aspect is to educate flexible examiners that are not dependent solely on standardized image uptake positions. Examiners need to learn how to gain access to information on structures from non-standardized angles and in cases when US does not provide information about the target organ due to the presence of fat, bone or air. This aspect can be also effectively addressed by illustrated ultrasound and again without presence of experienced personal. The trainee is asked to identify a particular structure from one probe position. Then her task is to identify other positions that can be used as an alternative in case if the preferred for some reason is not accessible on a particular patient. If the trainee gets disoriented during the exploration, she can easily correct her interpretation with the preferred additional overlay.

These examples demonstrate the high utility factor of illustrated ultrasound as additional component in the US examination training. We believe that adding such a component to the examiner skills build-up phase can lead to shorter learning period and will train examiners to be more flexible in interpretation of non-standard image uptakes.

8. Conclusions

In this paper we have proposed an enhancement of US liver examinations that are enriched with higher semantics originating from co-registered CT modality. The paper puts into focus the application of illustrative visual cues. For systems where a segmentation and registration are already available, illustrated ultrasound concept can be easily integrated to assist the interpretation of liver examinations. In addition, the paper proposes a complete all-in-one visual computing pipeline, including Couinaud segmentation and registration stages which are fast and easy to perform.

Illustrated ultrasound is aligned with our clinical setting, standardized US examination procedures and challenges that we daily face in the clinical routine. All stages of proposed pipeline are designed to keep user in the loop and do not aim at replacing her. The interactive fast segmentation and registration are approximative to provide orientation cues in complex anatomical arrangement of the liver organ. The visual enhancement with illustrated ultrasound is assisting the user in examination interpretation, the interpretation as such is performed by the user herself.

Acknowledgements

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