Faculty of Computer Science and Media Technology
Norwegian University of Science and Technology

Intra-operative Image Enhancement and Registration for Image Guided Laparoscopic Liver Resection

PhD Research Proposal

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1 Introduction

Liver cancer is one of the most common types of cancer. Surgical resection is generally accepted as the standard of care for liver cancer. In the past decade, with the technological advances in laparoscopic devices, medical imaging and the demand for minimally invasive approaches have led to an increase in the number of laparoscopic liver resection [1]. During a laparoscopic liver resection, a number of small incisions are made by the oncologist, then a needle is inserted to expand the abdomen with carbon dioxide gas to allow room for other instruments. The oncologist uses specialized instruments for example telescope, ultrasonic probe to visualize the abdominal cavity and to remove the cancerous part of the liver.

Although this minimally invasive surgery has provided great benefits to patients, it increases the operation difficulty as a result of the limited field of view, poor depth perception and lack of the sense of touch. Fortunately, the advances in medical imaging and computing over the last twenty years enabled the use of navigation systems in surgery. These systems, ultimately based on image pre-processing, tracking, visualization and 3D modeling techniques, increase the ability of the surgeon to perform surgery safely and accurately.

The aim of this research is to advance on image guided laparoscopic liver resection with a focus on image enhancement and intra-operative registration.

2 Background

2.1 Laparoscopic Liver Resection

Liver resection is removing part or all of a liver surgically which may help to prevent the disease from spreading more. It's one of the treatments for certain cases of colorectal liver metastases, some types of liver cancer or recurrent tumor [2].

In general surgery, liver resection has been regarded as one of the most challenging and difficult operations. Liver failure, haemorrhage, related sepsis and bile leakage are the main challenges for a successful liver surgery. In the last decades, a significant improvement has been achieved with advances of surgical techniques.

Liver tumor resection can either be operated by anatomical resection or non-anotomical resection. Anatomical resection is based on the understanding of the functional segmentation anatomy of the liver. In Coinaud [3], the author first proposed the segmentation of the liver, as shown in Figure 1 [4]. Each segment has its own portal vein, hepatic artery and biliary drainage, thus the segmental distribution can be used for planing and operating the surgery. This method can help avoid major vessels, less bleeding and reduces possibility of leaving ischaemic tissues behind. Non-anatomical is a method when the resection is performed arbitrarily which can be used for peripheral or superficial lesions, or when the lesion is distributed in multiple segments etc [5].

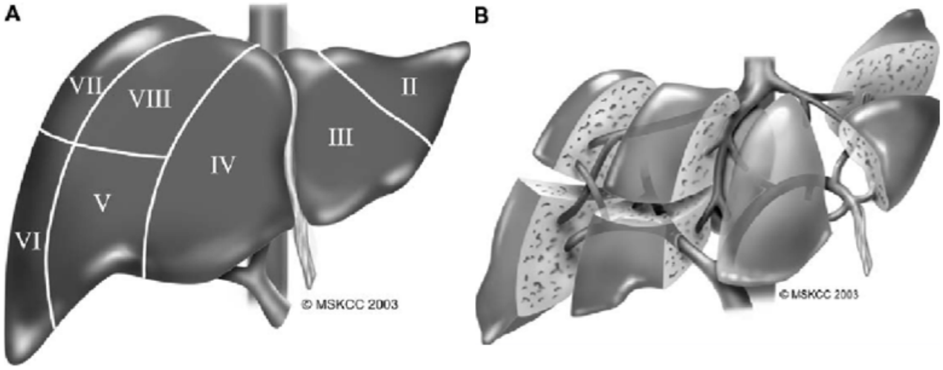

Figure 1: Liver Segmental Anatomy. (A) The eight segments of the liver. (B) Each segment has independent portal venous supply and (not shown) hepatic arterial supply [3] [4].

Laparoscopic techniques have greatly changed abdominal surgery as well as the liver resection in the past twenty years. It is a typical minimally invasive surgical procedure which has lots of advantages versus the open surgery.

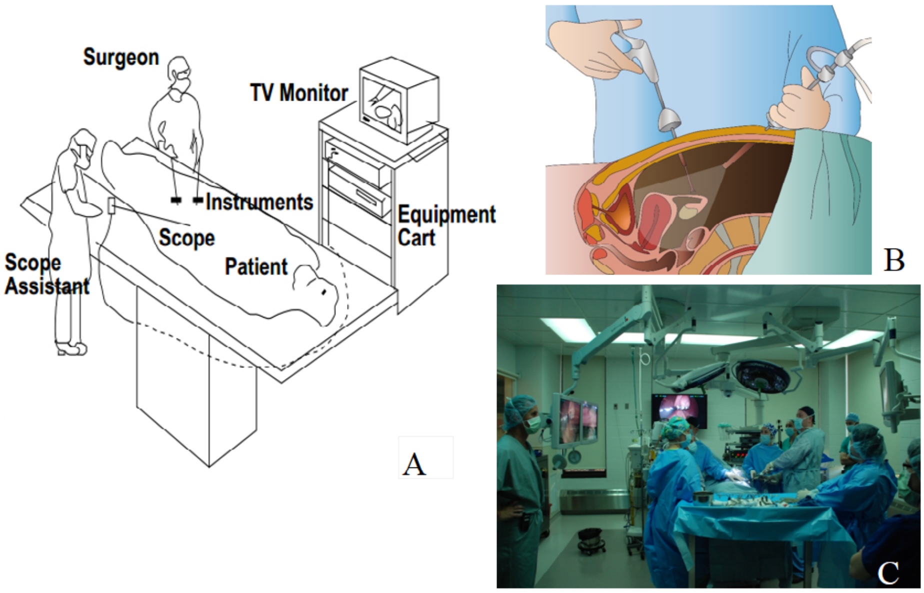

Figure 2: Traditional laparoscopy. (A) Illustration of a traditional laparoscopy performed by a surgeon and a scope assistant. (B) Instruments are inserted in the patient's body through small incisions. (C) A traditional laparoscopy surgery is performed in a operation room. Figure courtesy of [6] [7] [8].

The traditional mode of laparoscopic surgery is shown in Figure 2. In laparoscopic surgery the surgeon inserts instruments and video-laparoscope inside the patient's body through small incisions (Figure 2(B)). The operation is performed under the guidance of the images displayed on a screen (Figure 2(C)). The key component is the video-laparoscopy which is a combination of a video camera or charge-coupled device (CCD) and a fiber optic system. The fiber optic system is connected to a light source, then the operation field can be illuminated and then images inside the abdomen captured (Figure 2(B)). During a surgery, the laparoscope is held and controlled by a assistant under the command from the surgeons (Figure 2(A)). The deficiencies include the suboptimal and unstable views caused by the hand trembling and incorrect focus view.

2.2 Navigation of Laparoscopic Liver Resection

In order to overcome those disadvantages of traditional method, the robot laparoscopic surgery is introduced and commercially used recently. Figure 3(A) displays how the automated scope positioning system (AESOP) works [6]. The scope is held by a robot instead of a human. The surgeons can control the robot through a hand/foot controller. Figure 3(B) is a state-of-the-art technique: minimally invasive da Vinci Surgery. Except the techniques used for AESOP, it also has a high-definition 3D camera. The surgeon can be seated comfortably at the console of the da Vinci Surgical System and control the the instruments precisely with a high-resolution 3D view of the patient's body.

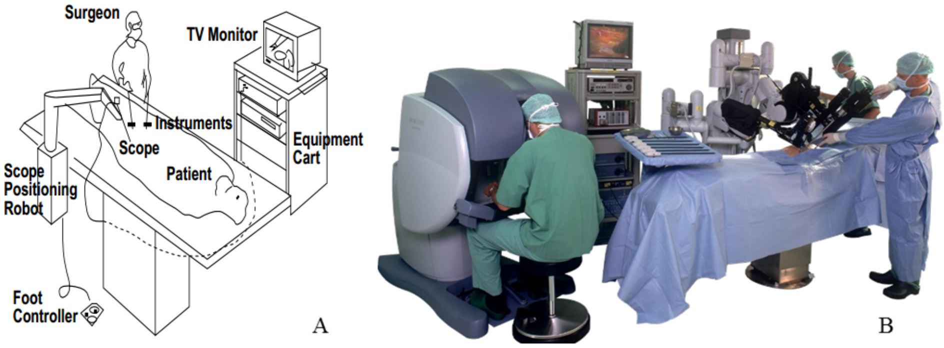

Figure 3: Robotically-assisted laparoscopy. (A) AESOP. (B)da Vinci Surgical System. Figure courtesy of [6] and Intuitive Surgical, Inc.

Modern computer-based systems are introduced in the Operation Room to help surgeons to both perform the surgical plan and guide the surgery. The first navigation system for Laparoscopic surgery is proposed in [9], they use a 3D model of the aorta as the main visual information and display the position and orientation of laparoscopic ultrasound images to the surgeon in real time. Other image modolities like pre-operative CT or MRI, together with intra-oprative ultrasound techniques, video promote the development of navigation systems.

In a navigation system, a 3D model is constructed by CT or MRI in the pre-operative stage, as shown in Figure 4 (A). Different anatomical areas are labeled and segmented in the model, which can present more intuitive visual information to the surgeon. A virtual resection is performed on the model to minimize the risk while maximizing the possibility to keep healthy functional tissue.

In the intra-operative stage, the 3D model is aligned with the real organ to establish a direct relationship between the clinical reality and virtual plan. Besides, the instrument is also tracked in some systems and presented in the virtual model (Figure 4 (B)).

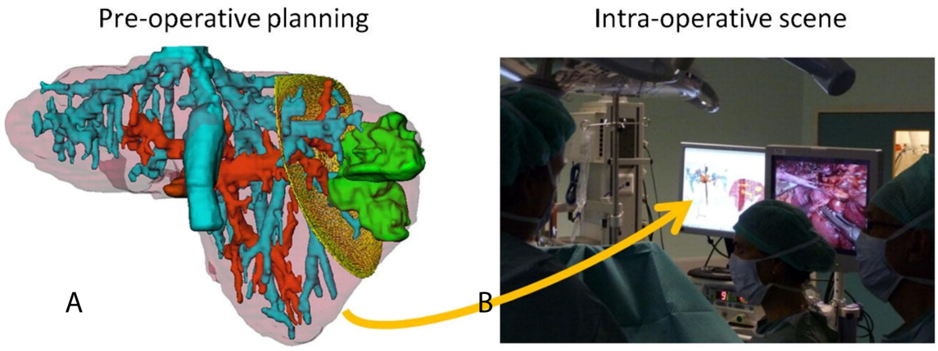

Figure 4: Navigation in Liver Surgery. (A) Pre-operative liver model. (B) Intra-operative scene, the surgeon has both a 3D and a cut-through view [10].

3 Research Proposal

Image guided interventions are medical procedures that use computer-based systems to provide virtual image overlays to help the physician precisely visualize and target the surgical site which has been greatly expanded by the advances in medical imaging and computer science techniques [11]. Laparoscopic liver surgery has been benefited by this development. The navigated laparoscopic liver surgery procedures can be summarized in Figure 5. The component technologies include 3D modeling, tracking, registration, visualization. The research program hereby is concerned with intra-operative registration.

Soft tissue deformation and shift during surgical intervention is one of the major challenges in image-guided surgery (which can impede the advancement of it). The utility of pre-operative surgical plan can be reduced by these deformations and may cause inaccuracies. Fortunately, some intra-operative imaging techniques and registration methods have been introduced to compensate the deformation. Intra-operative imaging using a wide range of technologies can provide a rich source of spatial information that can be used to provide feed-back of any patient movement or tissue deformation. It can be used for registration as well as providing inputs to models of soft tissue deformation that will permit update of the surgical plan to conform to these deformation.

Typically stereo video and ultrasound images can be obtained during surgery considering the acquisition time and radiation exposure to patients and doctors. The purpose of this research project is to develop enhancement algorithms for stereo video and ultrasound images, and registration techniques between intra-operative images of ultrasound or stereo endoscopy and pre-

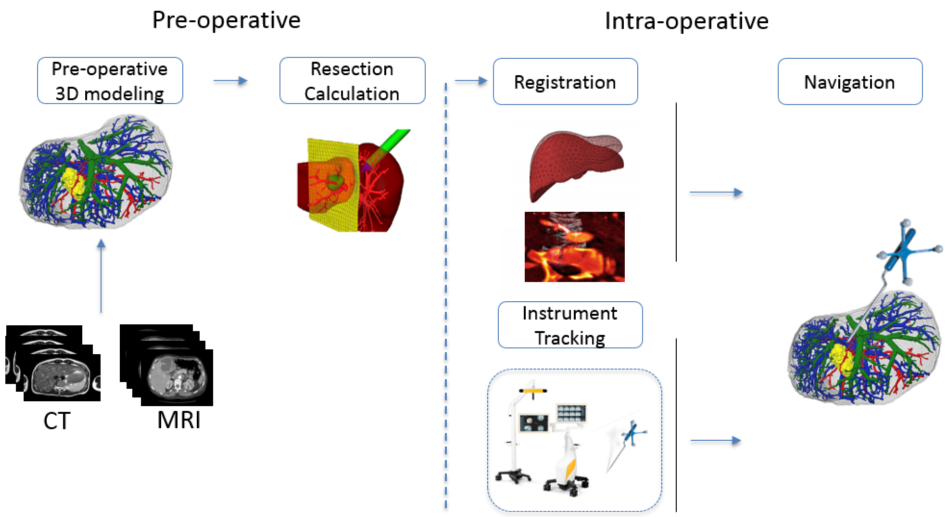

Figure 5: Procedures of a Navigated Laparoscopic Liver Surgery

operative 3D model constructed from MRI/CT.

3.1 Brief State-of-the-Art

3.1.1 Stereo Video and Ultrasound Image Enhancement

The artifacts during the laparoscopic video acquisition process and the characteristics of laparoscopic domain make many common image enhancement methods not feasible for stereo laparoscopic video. Those artifacts and specificities include smoke, lens fogging and blood pools, moist homogenous tissues, dynamic illumination conditions, non-rigid deformation due to the patient and surgeon motion, specular reflections etc [12].

The choice of the processing methods depends on the enhancement purpose. Most stereo video enhancement methods aim for a better depth perception for human being. Only few works presented for a better registration or reconstruction purposes. For example, in [13], linear structures which correspond to bony ridges are enhanced and then used for 2D to 3D registration purpose. In [14], two image filter based pre-processing techniques are presented for endoscopic feature tracking. The first process aims at contrast adjustment by histogram equalization and the second applys a morphological operator to improve image corners and edges. Similarly, histogram equalization combined with an edge preserving process is proposed for endoscopic images enhancement in [15]. In [16], the author combines the sharpness enhancement method [17] with natural rendering of color image based on retinex technique [18] which can ameliorating local image details (edges and corners of the endoscopic structure/vessels) for stereo endoscopic image matching.

In [19], the authors present a method to expand the small, restricted view of endoscopes with previously observed imagery. Similiar method also presented in [20]. The expanded surface image can be integrated with reconstruction techniques for a better presentation of tissue surface and ~~enhance the~~ visualization of navigated minimally invasive surgery.

The non-invasive nature, low cost and capability of forming real time imaging make ultrasound imaging a crucial role in medical imaging. However, ultrasound image contains more noise content than any other imaging modality especially speckle noise making it an ongoing challenge in many applications. Speckle is a particular type of noise which can affect all coherent imaging systems. For ultrasound imaging, the speckle noise degrades the fine details and edge definition and limits the contrast resolution by making ~~it~~ difficult to detect small and low contrast lesions in body [21]. Ultrasound enhancement methods can be classified to pre-processing which is for the signal generation and image acquisition stages and post-processing techniques which on the other hand is to enhance the images by sigmal processing algorithms [22]. For post-processing techniques, there are plenty of works proposed for enhancing the quality of ultrasound images especially for de-speckling. The methods are classified to (a) Single scale image filtering (b) Multi-scale methods and (c) ~~Methods of~~ soft computing ~~in~~ [21].

Single scale image filtering are those methods based on spatial and frequency domain filters. For example, in [23] Richard *et al.* present a median filer adaptation method to the problem of boundary-preserving speckle reduction in ultrasound images. A comparative study on different spatial domain filters for speckle noise reduction is presented in [24]. Multi-scale methods typically transform the original monochrome image into a multi-resolution hierarchy representation, then separately processing the images at each scale. In [25], a laplacian pyramid is used as the multi-scale representation, speckle is removed by nonlinear diffusion filtering of band pass ultrasound images in Lapacian pyramid domain. The third catogery utilizes the soft computing priciples such as Artificial Neural Networks, Genetic Algorithms for noise reduction [26] [27].

3.1.2 Intra-operative Registration

Image registration is the process of transforming different sets of data into one coordinate system [28]. For clinical scenario, registration mostly means pre-operative images aligned with the patient on the procedure table. In image guided laparoscopic liver surgery system, surface registration is critical which can provide essential guidance information to surgeons and the surface displacement information can be used for deformation correction [29]. Figure 6 shows an example of surface registration. The red model is constructed from segmented CT data and the blue surface is a partial intra-operative surface obtained from stereo endoscopic images [30]. Figure 7 shows a registration between the pre-operative data and live ultrasound image plane [31].

The main challenges when registering the pre-operative 3D model with the intra-operative laparoscopic images are [32]:

- Laparoscopic camera's small view field.
- Lack of cross modality landmarks.

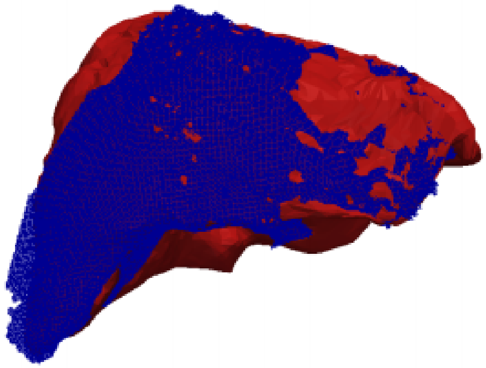

Figure 6: Registration between pre-operative liver model (red) and reconstructed intra-operative surface (blue) [30].

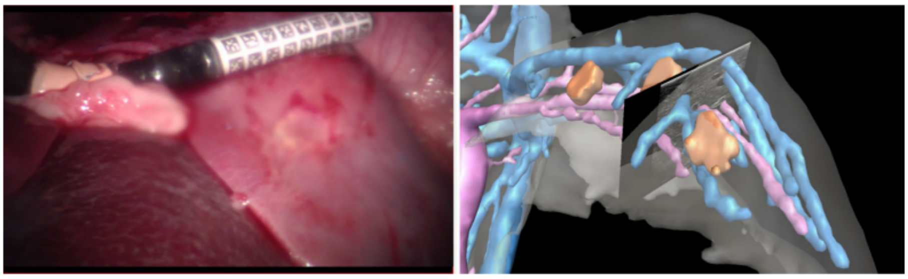

Figure 7: The pre-operative anatomical model derived from CT data is visualized within the context of live laparoscopic video and ultrasound data [31].

- The initial organ shift and tissue deformation caused by the insufflation.
- Continuous deformation caused by respiration and tool-tissue interaction.

Registration is broadly classified into two types: rigid registration which has been used in commercial image-guided systems and nonrigid registration. In clinical practice, rigid method has proven successful in spine and brain surgery. However, for the abdomen surgical procedures, the rigid-models are not sufficient. Thus, nonrigid methods have been in focus and developed for image guided liver surgery [11].

Registration methods were first introduced to open liver surgerys. In [33] [34] surface-based techniques are presented for open surgery. The intra-operative data is first obtained by optical tracked probe, then laser ragne scanner (LRS) is proposed for intra-operative modality which can provide ~~spartially~~ dense, textured delineations [35].

In 2003, James *et al.* [36] proposed a navigation system for laparoscopic surgery in abdomen in which the position and orientation of laparoscopic ultrasound images are disaplayed in real time to the surgeon. The pre-operative volume data is recorded by a landmark based method for intra-operative registration. This can be regarded as the first navigation system for laparoscopic surgey [37]. The regsitration methods are mostly based on register pre-operative MR or CT volume to intra-operative ultrasound images firstly. In [38], Penny *et al.* present a method to register a pre-operative MR volume to a sparse set of intra-operative ultrasound slices. The registration method is based on a vessel probability images obtained by the intensity values of MR and ultrasound images. More recently, in [36],an intra-operative 3D volume of the vessels is firstly reconstructed from laparoscopic ultrasound then registered to the pre-oprative 3D model.

Besides, other advanced types of intra-operative sensor data are introduced in laparoscopic surgery and bring advances for registration. In [39], LRS based registration in laparoscopic surgery is presented. In [40] stereo laparoscopes are introduced in liver surgery and the 3D video is used for registration recently. Structured light and time-of-flight are presented which are promising techniques for surface reconstruction and registration [41].

Multimodality image registration has been widely ~~researched recently.~~ In [42], the camera, laparoscopic instruments, and the intra-operative ultrasound scanner are calibrated and used to register the surface of the liver.

The most commonly used method to register the surfaces obtained by those intra-operative modality to the corresponding surface in the pre-operative model is the iterative closest point algorithm (ICP) or its variants [43]. Deformation models, statistical models, motion models and biomechanical models based nonrigid registration is discussed in [43]. In liver surgery, the studies begin with respiratory motion model [44] [45]. In [44], deformation models based on the response of a patient specific tissue mechanics are proposed. As ultrasonography allowing the acquisition of updated, real time information for tumor resection, some registration methods based on vascular features has been investigated, such as in [46], landmark-intersity information is used to perform 3D ultrasound-CT registration of liver. Besides, combination of rigid and nonrigid registrations also presented in [47].

3.2 Research Questions

3.2.1 Stereo Video and Ultrasound Image Enhancement

Stereo video and ultrasound is introduced in laparoscopic surgery which bring real time information during surgery. However the quality of images are often affected by unwanted noise, illumination, blurring and suffer from lack of contrast etc. Image enhancement is to improve the visual appearance quality for human observer or to better extract the features of images for image analysis systems. The former category include techniques to enhance contrast, remove noise, sharpen details, while the latter one can be edge/shape detection, objection segmentation as well as techniques used in the former [48] [49]. The principle objective of this task is to make the stereo and ultrasound images more suitable for registration in the next part by modifying the attributes of the images. This part focuses on the problem described below.

- What are the stereo video and ultrasound image enhancement techniques that are best suited for intra-operative liver registration?

3.2.2 Intra-operative Registration

In a surgery navigation system, the 3D model is obtained before surgery from CT and MRI. The anatomical shape and position of an organ changes when the surgery starts, further registrations are required to deploy pre-operative models during laparoscopic surgery. Aligning the intra-operative images with pre-operative volumes is one important step in a navigation system.

Our aims in this part is to develop registration techniques between intra-operative ultrasound images, stereo images captured by stereo endoscopy and pre-operative 3D models. The work aims at answering the following questions:

1. How to reconstruct the organ surface that can be employed for intra-operative registration purpose?
2. How to register the reconstructed organ surface with the pre-operative 3D volume?
3. How to improve the intra-operative registration by utilizing intra-operative ultrasound images and other data modalities such as instruments tracked by Optical Tracking System?

3.3 Methodology

3.3.1 Stereo Video and Ultrasound Image Enhancement

In this part, the focus will be on developing the state of the art methods of image enhancement techniques for better liver surface reconstruction and registration in laparoscopic liver resection application.

The recent introduction of high resolution stereo video in laparoscope presents an interesting source of information for performing navigation during surgery. There are diverse image enhancement methods including linear, nonlinear, pixel-based, multi-scale, fixed or adaptive [48]. Each method can serve some specific needs and limited to its own realm of applications. For example, the histogram equalization method which is based on a uniform histogram or gray-level probability density function, can't have good performance for medical images. Because many medical images have small gray-level differences between different tissue types [49].

In order to obtain relevant image features for laparoscopic stereo images, this project starts with investigating the existing image enhancement techniques and image enhancement methods which are for a better registration or reconstruction purpose, such as the methods presented in 3.1.1, especially the image enhancement method presented in [16] and view expansion methods presented in [19]and [20]. Then a new method will be developed based on those existing

No.	Research Questions	Task Objective	Research Approach
1	What are the state of the art methods for image enhancement for stereo video and ultrasound image in laparoscopic liver surgery?	Survey of enhancement methods.	Literature review.
2	Which kind of image enhancement method can be used for a better registration or reconstruction purpose?	Investigate features that can be used for registration and reconstruction.	Literature review, image analysis, programming.
3	Is it possible to develop a method to enhance laparoscopic liver image features for registration and reconstruction?	Existing algorithms implementation and modification, develop a robust algorithm.	Mathematical formulation, programming experiments.
4	What is the performance of the developed algorithm?	Implementation of the state of the art methods, comparison of the performance of the developed algorithm with the state of the art methods.	Implementation, objective evaluation.

Table 1: Methodology of Stereo Video and Ultrasound Image Enhancement Part.

algorithms for laparoscopic stereo images.

The state of the art and newly developed methods of stereo image will be evaluated by applying them to liver surface reconstruction and registration.

Similarly, enhancement has been researched for a long time for ultrasound images, but few work is for registration purpose. State of the art enhancement methods as reviewed in 3.1.1 will be investigated and ~~modified~~. The performance of the ~~modified~~ method will be evaluated by applying it to liver registration.

The datasets used will be acquired in Oslo University Hospital. Detail research questions and corresponding methodology are shown in Table 1.

3.3.2 Intra-operative Registration

Intra-operative registration of this PhD project include three parts: stereo vision based liver surface registration, ultrasound images registration and co-registration.

There are some ~~work~~ presented for 3D liver surface reconstruction~~, in~~ [50], a sparse surface data is reconstructed from 3D video for registration purpose~~, h~~owever, no registration work has been done. After further study of this area and according to the experimental conditions, stereo video will be used for liver surface registration in our research project.

The first part is to register the surface extracted from pre-operative CT/MRI data and surface reconstructed from stereo video. Surface extraction from pre-operative data can be achieved by existing algorithms, state of the art methods will be investigated and implemented in this part, ~~for example~~ marching cubes algorithm [51].

To reconstruct liver surface from stereo video needs several steps: stereo camera calibration, stereo matching and 3D reconstruction. Calibration using 3D or 2D calibration object approaches will be investigated and implemented, a proper method will be chosen according to the calibration error of the stereo laparoscope used. Stereo matching is a main part for reconstruction which is challenging as a result of the ambiguous and poor textured liver surface. Appropriate image features should be selected and presented for stereo matching. The enhancement result of previous part is the input of this step. A new stereo matching approach is expected to be proposed in this step possibly by ~~combing~~ the desirable traits of the existing ones. After the stereo camera calibration, the priori knowledge on the parameters of the stereo system include both intrinsic and extrinsic parameters are obtained, the reconstruction problem can be solved by triangulation unambiguously [52] based on the disparity map ~~get~~ from stereo matching. Other existing 3D reconstruction methods will be investigate and selected if this triangulation unambiguously method does not producing proper surface data.

There are many registration methods proposed in medical area and can be categorized according to various inherent properties: similarity criteria, optimization techniques, image modalities, mapping models, signal domains etc [53].

For the 3D video based surface registration and co-registration, similarity criteria methods such as ICP (Iterative Closest Point) which has been introduced in medical imaging as well as liver surgery [44] can be used as a first method to register the point cloud of reconstructed intra-operative 3D surface and 3D pre-operative surface because of the soft tissue properties of the liver surface. A new method based on ICP and surface feature extraction will be developed.

As stereo vision can only capture the features on the liver surface, ultrasonography is considered as an important compensation intra-operative modality for a liver resection for its capability of capturing features such as vessels, tumors deep in the liver. Some registration research is presented to align ultrasound with preoperative images in liver surgery [54] [55]. Therefore, in this project, ultrasound image is chosen to be an additional data ~~modiality~~ for registration.

For the ultrasound registration, we will mostly rely on the state-of-the art algorithms as presented in 3.1.2 as some existing methods have shown promising result. Such as the approach presented in [31]. Song *et al* register 2D ultrasound images to the 3D model by extracting vessel centre points. The result of this step will be part of the input of co-registration.

Besides, the OTS (Optical Tracking System, Polaris by NDI, Ontario, Canada) of a surgery navigation system (Brainlab AG, Munich, Germany) in Oslo University Hospital is able to precisely track a marker attached to the surgical instrument. This can ~~be~~ additional depth information acquisition approach which can be also used for registration.

No.	Research Questions	Task Objective	Research Approach
1	Which method can be used to extract the liver surface from pre-operative CT/MRI data?	Investigate methods that can extract surface from CT/MRI data.	Literature review, programming.
2	How to reconstruct the liver surface from intra-operative stereo images?	Existing algorithms implementation and modification, develop a robust algorithm for stereo matching.	Literature review, image analysis, programming.
3	How to register the surfaces?	~~Modification~~ of existing registration algorithms, develop a robust algorithm for laparoscopic liver surgery.	Literature review, mathematical formulation, programming experiments.
4	Which algorithms should be used for ultrasound images registration?	Survey on ultrasound registration and find out appropriate algorithm.	Literature review and programming.
5	How to combine the different data modality (stereo vision, ultrasound and OTS) for registration?	Develop ~~Rubost~~ algorithm.	Mathematical formulation, laboratory experiment and programming.
6	What is the performance of the developed registration algorithms?	Evaluation of the developed algorithms.	Objective evaluation experiment.

Table 2: Methodology of Intra-operative Registration Part.

The challenge of the co-registration part is to figure out ~~is~~ the ultrasound images and depth information from OTS can help to improve the intra-operative registration. In [56], stereo vision and doppler ultrasound are combined to estimate the brain shift and shows an eligible performance when applied them on a FEM (Finite Element Model). In this project, an algorithm ~~combined~~ ultrasound, stereo image and OTS data will be investigated to improve intra-operative registration performance.

The datasets used will be acquired in Oslo University Hospital. Detail research questions and corresponding methodology are shown in Table 2.

3.4 Ethical considerations

The patient data is used only for research purpose. The use of patient data will be always treated as anonymous and under the approval of The Data Protection Office at Oslo University Hospital, Rikshospitalet.

An application informing the scope, purpose and insights of this research will be submitted to the Regional Ethical Committee (Helse Sør-Øst) for its approval.

4 Project Plan

The research will be conducted in a period of three years. In the following subsections, a brief research plan, statement of supervision and work locations are given.

4.1 Research Plan

The materials and methods which will be employed during the research process has been presented in the previous section . This section details a work plan distributed in Work Packages (WPs). Such plan includes specific activities and the estimated time frame for its completion. A Gantt chart of the work distribution can be seen in Figure 8.

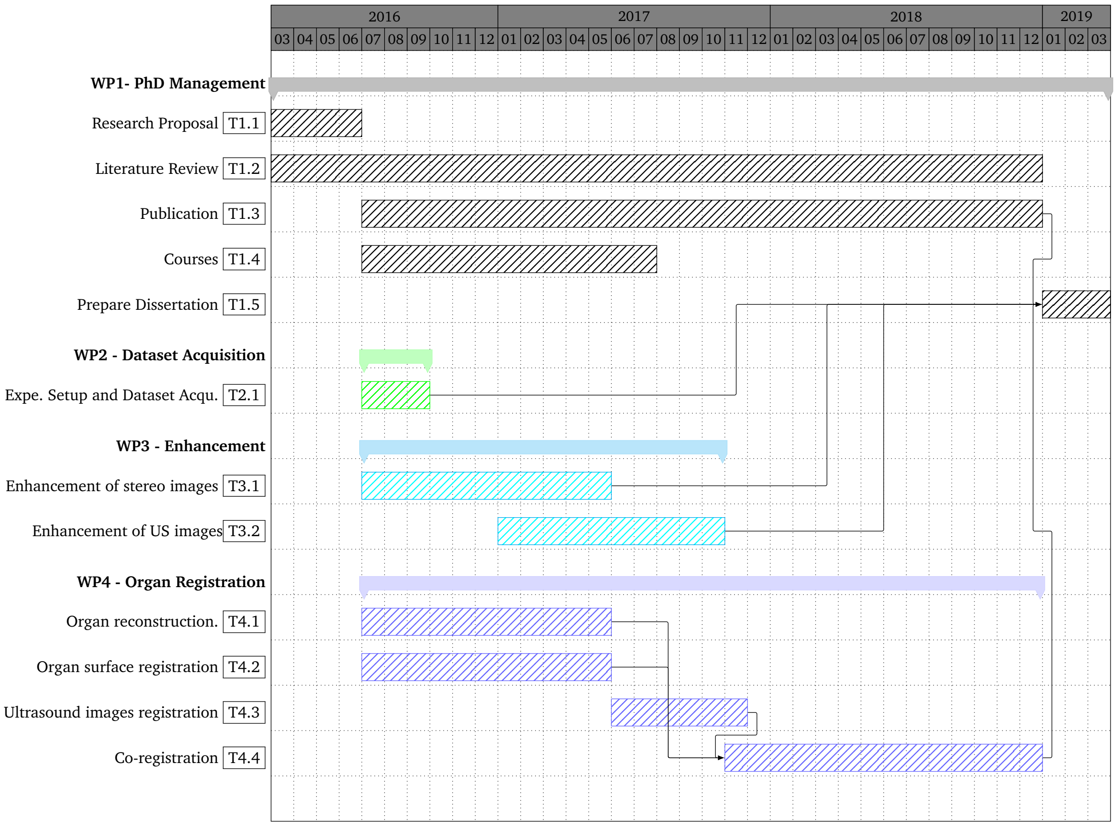

Figure 8: Gantt chart for the research project.

WP1 - PhD Management This work package is related to the organization of PhD program. It establishes the basis for the research and compile and prepare the scientific outcomes for the PhD dissertation.

T1.1 Research Proposal It will be delivered within the first 3 months of the research to the admission board at **Norwegian University of Science and Technology** for its approval.

T1.2 **Literature Review** The literature review will provide the basis to support the research process. Literature study will be conducted throughout the PhD program. The topics to be reviewed are:

- Image guided laparoscopic liver resection systems.
- Image enhancement for reconstruction/registration.
- Organ surface reconstruction.
- Video and ultrasound image registration methods.

T1.3 **Publications** This task is present throughout the PhD program. It consists of preparing all the scientific material and generate scientific publications. WP3 and WP4 yield the core scientific results. For each of these work packages, at least one scientific publications in a peer-reviewed journal/conference is expected.

T1.4 **Courses** As part of the PhD program, 30 ECTS theoretical curriculum is planned and will be taken at Norwegian University of Science and Technology i Gjøvik (NTNU i Gjøvik) and University of Oslo (UiO). As the PhD research project falls into the Image Processing Track, the compulsory courses are MNSES9100 Science, ethics and society and IMT6151 Selected Topics in Image Processing. The courses proposed in Table 3 will be undertaken. Detail description of the courses is given in Appendix A.

The motivation of choosing these courses is:

1. MNSES9100: Compulsory course, and the one in UiO is an one week intensive course which is quite suitable for PhD students.
2. IMT6151: Compulsory courses.
3. STK9900: This course provides insight on how to build a statistical model, how to analyse data and how to validate result. It is necessary for our PhD project. No similar course in NTNU i Gjøvik and it's a two weeks intensive course in UiO which makes it suitable to choose.
4. INF9305: This course is about image enhancement, segmentation, pattern recognition and image classification. Similar course in NTNU is in Trondheim which is unpracticality to take.

Code	Course	Institution	ECTS credits	Period
MNSES9100	Science, ethics and society	UiO	5	Autumn 2016
IMT6151	Selected topics in Image Processing	NTNU i Gjøvik	5	Autumn 2016
STK9900	Statistical methods and applications	UiO	10	Spring 2017
INF9305	Digital Image Analysis	UiO	10	Autumn 2016

Table 3: List of courses.

WP2 - Experiment Setup and Dataset Acquisition The task is the preparation of the research experiment environment clinically and acquire datasets for further study as well as for evaluation of the implemented methods. This is in collaboration with Oslo University Hospital.

WP3 - Enhancement This work package is an important part of the research project. The aim is to enhance the image quality before performing registration. It will mostly consist of literature review and algorithm implementation. The algorithms that will be studied include General image enhancement algorithms(starting from [21]), stereo video and Ultrasound image enhancement and application to reconstruction/registration and view expansion methods (starting from [57]). Enhancement is the pre-processing for a registration, and is researched together with registration. The outcomes will be submitted to Medical Imaging Computing and Computer Assisted Interventions (MICCAI), 2017.

WP4 - Organ Registration This work package is the core part of the research project. The aim is to perform organ registration using intra-operative laparoscopic video and ultrasound images. It will mostly consist of literature survey and algorithm implementation. The algorithms will be studied for:

- Organ surface reconstruction from intra-operative stereo video and pre-operative CT/MRI.
- Organ surface registration.
- Ultrasound images based registration.
- Co-registration based on reconstructed organ surface, intra-operative video, ultrasound images etc.

Two scientific publications at least are expected from this WP.

T4.1 **Organ surface reconstruction from intra-operative stereo video and pre-operative CT/MRI** The first part of this task is to obtain the surfaces used for registration. The intra-operative stereo video and pre-operative CT/MRI are used for organ surface reconstruction. The reconstructed sparse point clouds should present desirable properties for the registration step. Existing approaches will be studied and improved.

T4.2 **Organ suface registrtion** The soft tissue properties of the liver surface motivate us to use similarity criteria methods such as ICP as a first step to register the pre-operative 3D model's surface with the reconstructed organ surface. New methods should be proposed for registration based on the implementation and review of the state-of-the-art. The result of this task will be submitted to IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2017.

T4.3 **Ultrasound images registration** Ultrasound images registration has been studied for years. The purpose of this step is to study how the ultrasound be an useful additional information for a better registration. Therefore, we will rely on the existing algorithms which include implementation and validation on our datasets.

T4.4 **Co-registration** This step is to ultilize the outcome of the previous part (T 4.3, T 4.4), together with another data modality (Optical Tracking System) for a better navigation during the operation. The results of this task will be submitted to European Conference on Computer Vision (ECCV), 2018 and IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2018.

4.2 Work Location and Mobility Plan

The core work location of the PhD will be the Norwegian University of Science and Technology in Gjøvik where the PhD candidate is formally employed and Oslo University Hospital (Rikshospitalet) where the medical equipment and clinical team are located. Besides, mobility to Univ. Paris 13 is also planned (1 to 3 months each year) and under the collaboration frame of the three institutions (Norwegian University of Science and Technology, the Intervention Centre, and University of Paris 13)

4.3 Funding

This PhD program is fully funded by Norwegian University of Science and Technology under the project of IQ-MED.

4.4 Supervision

This research program will be supervised by:

- Main Internal Supervisor: Prof. Faouzi Alaya Cheikh, PhD. Norwegian University of Science and Technology.
- Main External Supervisor: Prof. Ole Jakob Elle, PhD. The Intervention Centre, Oslo University Hospital.
- Co-Supervisor: Prof. Azeddine Beghdadi, PhD. University of Paris 13, Paris, France.

4.5 Signatures

03.06.2016 Congcong Wang

Date and Signature, PhD Candidate (Congcong Wang)

03.06.2016

Date and Signature, Main Internal Supervisor (Faouzi Alaya Cheikh)

09.06.2016

Date and Signature, Main External Supervisor (Ole Jakob Elle)

09.06.2016

Date and Signature, Co-Supervisor (Azeddine Beghdadi)

References

[1] K, N., J, M., A, T., JL, S., T, G., & DA, G. 2011. Comparative benefits of laparoscopic vs open hepatic resection: A critical appraisal. *Archives of Surgery*, 146(3), 348–356. URL: +http://dx.doi.org/10.1001/archsurg.2010.248, arXiv:/data/Journals/SURG/5400/srv05005_348_356.pdf, doi:10.1001/archsurg.2010.248.

[2] Grundmann, R., Hermanek, P., Merkel, S., Germer, C., Hauss, J., Henne-Bruns, D., Herfarth, K., Hopt, U., Junginger, T., Klar, E., et al. 2008. [diagnosis and treatment of colorectal liver metastases-workflow]. *Zentralblatt fur Chirurgie*, 133(3), 267–284.

[3] Couinaud, C. 1957. *Le foie: études anatomiques et chirurgicales*. Masson & Cie.

[4] Liau, K., Blumgart, L., & DeMatteo, R. 2004. Segment-oriented approach to liver resection. *Surgical Clinics of North America*, 84(2), 543–561.

[5] Howard, E. 1998. Techniques in liver surgery.

[6] Uecker, D. R., Wang, Y., Lee, C., & Wang, Y. 1995. Laboratory investigation: automated instrument tracking in robotically assisted laparoscopic surgery. *Computer Aided Surgery*, 1(6), 308–325.

[7] Orford, J. 2016. What is laparoscopic surgery. http://www.sals.com.au/what-is-laparoscopic-surgery/#whatare.

[8] McPherson, C. 2011. Soft tissue (laparoscopy and thoracoscopy). http://infinitimedical.com/vetforum/soft-tissue-laparoscopy-thoracoscopy/.

[9] Ellsmere, J., Stoll, J., Rattner, D., Brooks, D., Kane, R., Wells, W., Kikinis, R., & Vosburgh, K. 2003. A navigation system for augmenting laparoscopic ultrasound. In *Medical Image Computing and Computer-Assisted Intervention-MICCAI 2003*, 184–191. Springer.

[10] Freudenthal, A., Stüdeli, T., Lamata, P., & Samset, E. 2011. Collaborative co-design of emerging multi-technologies for surgery. *Journal of biomedical informatics*, 44(2), 198–215.

[11] Cleary, K. & Peters, T. M. 2010. Image-guided interventions: technology review and clinical applications. *Annual review of biomedical engineering*, 12, 119–142.

[12] Sdiri, B., Beghdadi, A., Cheikh, F. A., Pedersen, M., & Elle, O. J. 2016. An adaptive contrast enhancement method for stereo endoscopic images combining binocular just noticeable difference model and depth information. *Electronic Imaging*, 2016(13), 1–7.

[13] Munbodh, R., Chen, Z., Jaffray, D. A., Moseley, D. J., Knisely, J. P., & Duncan, J. S. 2008. Automated 2d–3d registration of portal images and ct data using line-segment enhancement. *Medical physics*, 35(10), 4352–4361.

[14] Selka, F., Nicolau, S. A., Agnus, V., Bessaid, A., Marescaux, J., & Soler, L. 2013. Evaluation of endoscopic image enhancement for feature tracking: a new validation framework. In *Augmented Reality Environments for Medical Imaging and Computer-Assisted Interventions*, 75–85. Springer.

[15] Pizer, S. M., Amburn, E. P., Austin, J. D., Cromartie, R., Geselowitz, A., Greer, T., ter Haar Romeny, B., Zimmerman, J. B., & Zuiderveld, K. 1987. Adaptive histogram equalization and its variations. *Computer vision, graphics, and image processing*, 39(3), 355–368.

[16] Sdiri, B., Cheikh, F. A., Dragusha, K., & Beghdadi, A. 2015. Comparative study of endoscopic image enhancement techniques. In *Colour and Visual Computing Symposium (CVCS), 2015*, 1–5. IEEE.

[17] Beghdadi, A. & Le Negrate, A. 1989. Contrast enhancement technique based on local detection of edges. *Computer Vision, Graphics, and Image Processing*, 46(2), 162–174.

[18] Chen, S. & Beghdadi, A. 2009. Natural rendering of color image based on retinex. In *Image Processing (ICIP), 2009 16th IEEE International Conference on*, 1813–1816. IEEE.

[19] Totz, J., Fujii, K., Mountney, P., & Yang, G.-Z. 2012. Enhanced visualisation for minimally invasive surgery. *International journal of computer assisted radiology and surgery*, 7(3), 423–432.

[20] Mountney, P. & Yang, G.-Z. 2009. Dynamic view expansion for minimally invasive surgery using simultaneous localization and mapping. In *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, 1184–1187. IEEE.

[21] Ragesh, N., Anil, A., & Rajesh, R. 2011. Digital image denoising in medical ultrasound images: a survey. In *Icgst Aiml-11 Conference, Dubai, UAE*, volume 12, 14.

[22] Ortiz, S. H. C., Chiu, T., & Fox, M. D. 2012. Ultrasound image enhancement: A review. *Biomedical Signal Processing and Control*, 7(5), 419–428.

[23] Czerwinski, R. N., Jones, D. L., & O'Brien Jr, W. D. 1995. Ultrasound speckle reduction by directional median filtering. In *Image Processing, 1995. Proceedings., International Conference on*, volume 1, 358–361. IEEE.

[24] Thangavel, K., Manavalan, R., & Aroquiaraj, I. L. 2009. Removal of speckle noise from ultrasound medical image based on special filters: comparative study. *ICGST-GVIP Journal*, 9(3), 25–32.

[25] Zhang, F., Yoo, Y. M., Koh, L. M., & Kim, Y. 2007. Nonlinear diffusion in laplacian pyramid domain for ultrasonic speckle reduction. *Medical Imaging, IEEE Transactions on*, 26(2), 200–211.

[26] Park, H. & Nishimura, T. 2007. Reduced speckle noise on medical ultrasound images using cellular neural network. In *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2138–2141. IEEE.

[27] Thavavel, V., Basha, J. J., & Murugesan, R. 2010. Withdrawn: A novel intelligent wavelet domain noise filtration technique: Application to medical images. *Expert Systems with Applications*.

[28] Wikipedia. 2016. Image registration. https://en.wikipedia.org/wiki/Image_registration.

[29] Paulsen, K. D., Ji, S., Hartov, A., Fan, X., & Roberts, D. W. 2012. Integration of 3d intraoperative ultrasound for enhanced neuronavigation. In *SPIE Medical Imaging*, 83200S–83200S. International Society for Optics and Photonics.

[30] Suwelack, S. 2015. *Real-time Biomechanical Modeling for Intraoperative Soft Tissue Registration*. KIT Scientific Publishing.

[31] Song, Y., Totz, J., Thompson, S., Johnsen, S., Barratt, D., Schneider, C., Gurusamy, K., Davidson, B., Ourselin, S., Hawkes, D., et al. 2015. Locally rigid, vessel-based registration for laparoscopic liver surgery. *International journal of computer assisted radiology and surgery*, 10(12), 1951–1961.

[32] Mountney, P., Fallert, J., Nicolau, S., Soler, L., & Mewes, P. W. 2014. An augmented reality framework for soft tissue surgery. In *Medical Image Computing and Computer-Assisted Intervention–MICCAI 2014*, 423–431. Springer.

[33] Herline, A. J., Stefansic, J. D., Debelak, J. P., Hartmann, S. L., Pinson, C. W., Galloway, R. L., & Chapman, W. C. 1999. Image-guided surgery: preliminary feasibility studies of frameless stereotactic liver surgery. *Archives of Surgery*, 134(6), 644–650.

[34] Herline, A. J., Herring, J. L., Stefansic, J. D., Chapman, W. C., Galloway, R. L., & Dawant, B. M. 2000. Surface registration for use in interactive, image-guided liver surgery. *Computer Aided Surgery*, 5(1), 11–17.

[35] Cash, D. M., Sinha, T. K., Chapman, W. C., Galloway Jr, R. L., & Miga, M. I. 2002. Fast accurate surface acquisition using a laser range scanner for image-guided liver surgery. In *Medical Imaging 2002*, 100–110. International Society for Optics and Photonics.

[36] Ellsmere, J., Stoll, J., Rattner, D., Brooks, D., Kane, R., Wells, W., Kikinis, R., & Vosburgh, K. 2003. A navigation system for augmenting laparoscopic ultrasound. In *Medical Image Computing and Computer-Assisted Intervention-MICCAI 2003*, 184–191. Springer.

[37] Kleemann, M., Deichmann, S., Esnaashari, H., Besirevic, A., Shahin, O., Bruch, H.-P., & Laubert, T. 2012. Laparoscopic navigated liver resection: technical aspects and clinical practice in benign liver tumors. *Case reports in surgery*, 2012.

[38] Penney, G. P., Blackall, J. M., Hamady, M., Sabharwal, T., Adam, A., & Hawkes, D. J. 2004. Registration of freehand 3d ultrasound and magnetic resonance liver images. *Medical image analysis*, 8(1), 81–91.

[39] Kingham, T. P., Jayaraman, S., Clements, L. W., Scherer, M. A., Stefansic, J. D., & Jarnagin, W. R. 2013. Evolution of image-guided liver surgery: transition from open to laparoscopic procedures. *Journal of Gastrointestinal Surgery*, 17(7), 1274–1282.

[40] Kunert, W., Storz, P., & Kirschniak, A. 2013. For 3d laparoscopy: a step toward advanced surgical navigation: how to get maximum benefit from 3d vision. *Surgical endoscopy*, 27(2), 696–699.

[41] Maier-Hein, L., Mountney, P., Bartoli, A., Elhawary, H., Elson, D., Groch, A., Kolb, A., Rodrigues, M., Sorger, J., Speidel, S., et al. 2013. Optical techniques for 3d surface reconstruction in computer-assisted laparoscopic surgery. *Medical image analysis*, 17(8), 974–996.

[42] Paulsen, K. D., Ji, S., Hartov, A., Fan, X., & Roberts, D. W. 2012. Integration of 3d intraoperative ultrasound for enhanced neuronavigation. In *SPIE Medical Imaging*, 83200S–83200S. International Society for Optics and Photonics.

[43] Hawkes, D. J., Barratt, D., Blackall, J. M., Chan, C., Edwards, P. J., Rhode, K., Penney, G. P., McClelland, J., & Hill, D. L. 2005. Tissue deformation and shape models in image-guided interventions: a discussion paper. *Medical Image Analysis*, 9(2), 163–175.

[44] Rucker, D. C., Wu, Y., Clements, L. W., Ondrake, J. E., Pheiffer, T. S., Simpson, A. L., Jarnagin, W. R., & Miga, M. I. 2014. A mechanics-based nonrigid registration method for liver surgery using sparse intraoperative data. *Medical Imaging, IEEE Transactions on*, 33(1), 147–158.

[45] Rohlfing, T., Maurer Jr, C. R., O'Dell, W. G., & Zhong, J. 2004. Modeling liver motion and deformation during the respiratory cycle using intensity-based nonrigid registration of gated mr images. *Medical physics*, 31(3), 427–432.

[46] Lange, T., Papenberg, N., Heldmann, S., Modersitzki, J., Fischer, B., Lamecker, H., & Schlag, P. M. 2009. 3d ultrasound-ct registration of the liver using combined landmark-intensity information. *International journal of computer assisted radiology and surgery*, 4(1), 79–88.

[47] Clements, L. W., Dumpuri, P., Chapman, W. C., Galloway, R. L., & Miga, M. I. 2007. Atlas-based method for model updating in image-guided liver surgery. In *Medical Imaging*, 650917–650917. International Society for Optics and Photonics.

[48] Bankman, I. N. 2000. Preface. In *Handbook of Medical Imaging*, BANKMAN, I. N., ed, Biomedical Engineering, xi – xii. Academic Press, San Diego. URL: http://www.sciencedirect.com/science/article/pii/B9780120777907500011, doi:http://dx.doi.org/10.1016/B978-012077790-7/50001-1.

[49] Rangayyan, R. M. 2000. Introduction to enhancement. In *Handbook of Medical Imaging*, BANKMAN, I. N., ed, Biomedical Engineering, 1 – 2. Academic Press, San Diego. URL: http://www.sciencedirect.com/science/article/pii/B9780120777907500035, doi:http://dx.doi.org/10.1016/B978-012077790-7/50003-5.

[50] Röhl, S., Bodenstedt, S., Suwelack, S., Kenngott, H., Müller-Stich, B. P., Dillmann, R., & Speidel, S. 2012. Dense gpu-enhanced surface reconstruction from stereo endoscopic images for intraoperative registration. *Medical physics*, 39(3), 1632–1645.

[51] Lorensen, W. E. & Cline, H. E. 1987. Marching cubes: A high resolution 3d surface construction algorithm. In *ACM siggraph computer graphics*, volume 21, 163–169. ACM.

[52] Trucco, E. & Verri, A. 1998. *Introductory techniques for 3-D computer vision*, volume 201. Prentice Hall Englewood Cliffs.

[53] Khalifa, F., Beache, G. M., Gimel'farb, G., Suri, J. S., & El-Baz, A. S. 2011. State-of-the-art medical image registration methodologies: a survey. In *Multi modality state-of-the-art medical image segmentation and registration methodologies*, 235–280. Springer.

[54] Fusaglia, M., Tinguely, P., Banz, V., Weber, S., & Lu, H. 2016. A novel ultrasound-based registration for image-guided laparoscopic liver ablation. *Surgical innovation*.

[55] Song, Y., Totz, J., Thompson, S., Johnsen, S., Barratt, D., Schneider, C., Gurusamy, K., Davidson, B., Ourselin, S., Hawkes, D., et al. 2015. Locally rigid, vessel-based registration for laparoscopic liver surgery. *International journal of computer assisted radiology and surgery*, 10(12), 1951–1961.

[56] Mohammadi, A., Ahmadian, A., Azar, A. D., Sheykh, A. D., Amiri, F., & Alirezaie, J. 2015. Estimation of intraoperative brain shift by combination of stereovision and doppler ultrasound: phantom and animal model study. *International journal of computer assisted radiology and surgery*, 10(11), 1753–1764.

[57] Mountney, P. & Yang, G.-Z. 2009. Dynamic view expansion for minimally invasive surgery using simultaneous localization and mapping. In *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, 1184–1187. IEEE.

A Detail description of the proposed courses

A.1 Science, ethics and society (MNSES9100)

- 5 ETCS Credits
- PhD level
- Every Spring and Autumn
- http://www.uio.no/studier/emner/matnat/ifi/MNSES9100/

Course Content The course takes a critical and analytical look at the role of science and technology in modern society. Questions addressed include: What is science? How does it differ from other disciplines? Which ethical responsibilities do scientists have to their peers and the public? How should society manage technological risk? What is the role of education, the media, industry and government on the progress of science and technology?

The course covers three main topics:

- philosophy of science;
- research ethics;
- and science and society. Examples and case studies will be taken from all areas of science and technology.

Learning Outcome The course will contribute to the student's appreciation of the place and role of science in a modern society, as well as a broad insight into the way science and scientists are perceived and studied within other disciplines such as philosophy, ethics and sociology. Course literature ranges from classic works in philosophy of science and research ethics, to topical cases drawn from the international and national media. The analysis and discussion of case studies forms a central part of the course, particularly in research ethics. Teaching comprises both lectures and small group discussions.

Teaching Teaching runs as an intensive course over one week in October/November with 20 hours of lectures and 12 hours of group discussions and seminars. 2-3 weeks after the course there will be a follow-up seminar for students to present, discuss and get feedback on their chosen essay topics.

Examination A written essay of 6-9 pages.

A.2 Selected topics in Image Processing(IMT6151)

- 5 ETCS Credits
- PhD level
- Every Spring and Autumn
- http://english.hig.no/course_catalogue/student_handbook/2015_2016/courses/avdeling_

for_informatikk_og_medieteknikk/imt6151_selected_topics_in_image_processing

Course Content Recent advances in image processing including adaptive and real-time algorithms, multi-scale techniques, HVS inspired approaches, multi-view image processing, lightfield imaging, etc.

Learning Outcome

Knowledge

- The candidate is in the forefront of knowledge within the fields of selected topics in image processing
- The candidate can evaluate the approprietness and applicability of advanced image processing methods in different application domains
- The candidate has the ability to discuss and explain advanced image processing methods

Skills

- The candidate can formulate possible advanced image processing solutions to different applications
- The candidate can implement advanced image processing algorithms

General competence

- The candidate has the ability to communicate and discuss recent research in advanced topics on image processing
- The candidate has the ability to evaluate other people work on advanced image processing techniques

Teaching

- Lectures
- Net Support Learning
- Project work
- Meeting(s)/Seminar(s)

Examination

- The candidate must provide one term paper and a final paper.
- The term paper he/she proposes novel ideas or applies one or more of the studied techniques to address a problem related to the candidates own thesis work.
- The final paper should be in the form of a scientific paper, including proposed novel idea(s)

supported by thorough discussion, experimental results and analysis, in a close to publishable scientific form.

- Both papers must be accepted to pass the course.

A.3 Statistical methods and applications (STK9900)

- 10 ETCS Credits
- PhD level
- Every Spring
- http://www.uio.no/studier/emner/matnat/math/STK9900/

Course Content The course provides insight on how to formulate a problem into statistical language, how to build a statistical model, how to analyse data and how to validate results. Regession methods (that is emperical determination of relations between variables) and other multivariable statistical techniques are central. In particular linear regression, analysis of variance, design of experiments, logistic regression, survival analysis and simple time-series analysis is treated.
Learning Outcome The students will become familiar with many important topics in applied statistics. Teaching will be computer assisted and related to examples. Mathematics is kept at a minimum, while it is expected that the students have a basic knowledge of statistics at the level of STK1000 - Introduction to applied statistics. Use of a software package is integraded into the course. The course is in particular directed towards master and phd students who need knowledge of statistics beyond an introductory course for their thesis work. The students are required to actively take part in practical exercises.
Teaching Teaching will be given intensively over two separate weeks, each day from 9.15 - 16.00.
Examination Depending on the number of students, the exam will be in one of the following four forms: 1. Only written exam. 2. Only oral exam. 3. A project paper followed by a written exam. 4. A project paper followed by an oral exam/hearing For the latter two the project paper and the exam counts equally and the final grade is based on a general impression after the final exam. (The two parts of the exam will not be individually graded.)
One compulsory assignment has to be approved, before the second week of teaching. Lectures, exercises and the compulsory assignment are given jointly for STK4900 and STK9900, but the exam questions are not the same for the two courses.

A.4 Digital Image Analysis (INF9305)

- 10 ETCS Credits
- PhD level
- Every Autumn
- http://www.uio.no/studier/emner/matnat/ifi/INF9305/index.html

Course Content Digital images and their properties. Data structures for image analysis. Construction of 2D and 3D filters for image enhancement and analysis. Segmentation and description of objects in images. Pattern recognition. Supervised and unsupervised classifi-

cation.
Learning Outcome The student will bet a basic understanding of concepts, methods and applications of image analysis, pattern recognition, and image classification.
In addition, each PhD student will be given an extended curriculum within the field/research area of the course. The syllabus must be approved by the lecturer so that the student can be admitted to the final exam.
Teaching The course comprises 2 hours of lectures and 2 hours of exercises per week.
Examination Oral or written (4 hours) examination. All mandatory assignments have to be accepted in order to take the exam.