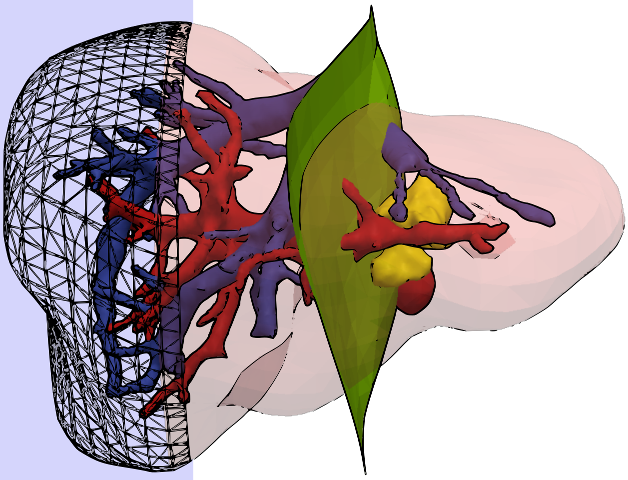
Research Proposal

Geometric Modeling for Planning and Navigation in Video-Assisted Surgery

- Applications to Laparoscopic Liver Resection -



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1 Introduction

Liver cancer is the fourth most common type of cancer. Surgical resection is generally accepted as the standard of care and may cure patients with colorectal metastases. Liver surgical resection is a complex procedure that needs to be performed very precisely, relying on a carefully prepared plan. Currently,surgical liver resection is increasingly being performed by laparoscopic approach.

Nowadays there exist modern computer-based systems that help surgeons to both perform the surgical plan and guide the surgery. These systems are based on patient-specific three-dimensional (**3D**) models generated from either *computed tomography* (**CT**) or *magnetic resonance imaging* (**MRI**). These 3D models play a double role during the extent of the procedure:

1. Providing tools to support the surgeon during the decision making and planning of the treatment (*Pre-operative stage*[1]).

2. Helping the surgeons to perform the resection according to the resection plan, minimizing the risks of the operation while maximizing the surgical outcome (*Intra-operative stage*[2]).

Along this document, the pre-operative stage will be referred to as **planning** and the intra-operative stage as **navigation**.

Three-dimensional models are typically obtained by using segmented anatomical regions previously extracted from either CT or MRI. 3D Surfaces are the fundamental elements to represent the anatomy of the liver (*parenchyma*, *vessels* and *tumor* regions), as well as the *virtual resection*. In the scientific literature, there have been a number of methods to generate 3D surfaces. Some of these methods have been already applied to not only liver surgical resection, but also to many interventional procedures like intravascular surgery, brain surgery and spine surgery among others.

The aim of the research presented in this document is to advance on image-guided surgery systems for laparoscopic liver surgery. The challenges targeted are enclosed in both planning and navigation, but with the common point of *geometric modeling* methods.

2 Background

2.1 Liver Tumor Resection

Liver resection is the treatment of choice in selected patients with colorectal metastasis [1] even in recurrent cases [2]. Liver resection is also important in other non-oncologic surgical procedures and living-donor programs.

Surgical liver resection is a procedure in which the tumor is separated and extracted from the rest of the healthy tissue in the liver. This procedure can be performed under either open surgery or laparoscopy surgery (through small incisions in the patient's skin). Either way, the challenges associated with this type of operation are:

- Guaranteeing a safety margin around the tumor (typically a rim of 10mm).

- Guaranteeing enough functional remnant liver tissue, which in case of healthy liver can be of 25-30% of the functional liver tissue.

- Reduction of bleeding, avoiding and controlling the cuts on the main vessels.

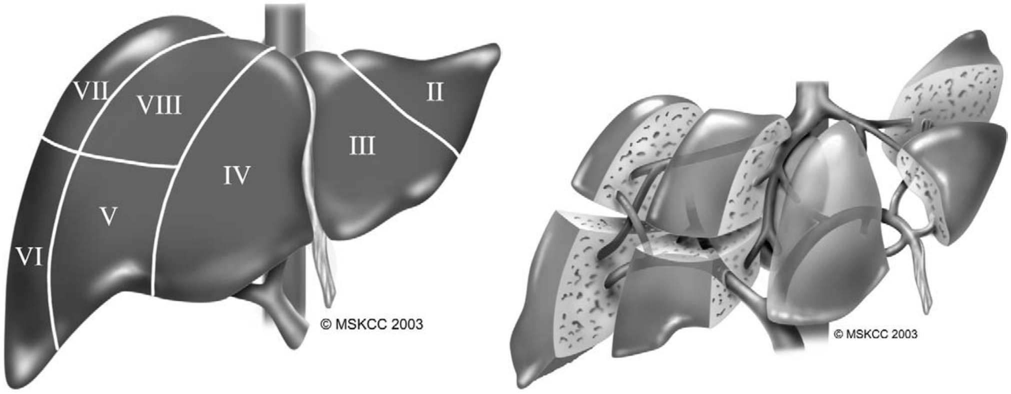
Liver tumor resection procedures can be classified into 1) *Anatomical* when one or more functional segments of the liver are resected; and 2) *Non-anatomical* when arbitrary pieces of the liver are resected. In scientific literature, there are several schemes for classifying the functional areas (segments of the liver) according to the drainage of the vessels. In Coinaud [3], the author proposed the first classification of the segments of the liver, this work allowed surgeons to perform anatomical liver resections. The classification consists of separating the liver in eight functional areas (Figure 1) according to the venous blood

[1] Days or weeks before the operation.

[2] During the operation.

supply. Recent works [4] and [5] provide deep information about terminology and classification of liver resections according to the functional areas to be resected.

The type of planning and the functional areas involved have an impact on the planning, and therefore, on the surgical outcome. New surgical techniques like *parenchymal-sparing*, where minimal *non-anatomical* resections are performed, are increasingly being used. The advantage of the *parenchymal-sparing* technique is that additional resections can be safely performed laparoscopically with good oncological outcome. Accurate planning and precise guidance during resection are crucial to this type of surgical techniques.



(a) Liver segments.

(b) Liver segments and their venous supply.

Figure 1: Liver functional segments as defined by Coinaud [3] (extracted from [6]).

2.2 Planning of Liver Surgical Resection

Nowadays, medical imaging modalities such as CT or MRI enable the creation of 3D patient-specific models, thus allowing personalized planning and guidance of the intervention. Independently of the modality employed, these 3D models can be divided in the following elements (Fig 2):

Parenchyma functional part of the liver which is perfused by the vessels system. One of the major concerns in liver resection is to leave intact as much healthy parenchyma as possible.

Vessels carrying the blood flow to irrigate the parenchyma, the most relevant type of vessels in liver resection are the veins. In liver, the veins can be separated in 1) *portal system* and 2) *hepatic system*. These systems are organized in tree-like structures. Avoiding certain vessels is not only the key to reduce complications like bleeding, but also to keep functional some parts of the liver.

Tumor which is the area to be resected. It is important that a security perimeter around the tumor is also resected, since a single tumor cell remaining has a risk of produce recurrence of tumor in other areas of the liver. Normally, a rim of 10mm around the tumor is considered a safe resection.

Virtual Resection represented as a surface, the *virtual resection* defines a separation between the part of the organ that is going to be resected and the rest of the organ. Based on this surface, volumetric statistics and intervention risk analysis can be performed. During navigation, the resection surface is the reference that guides the surgeons to precisely perform the resection.

Prior to the organ reconstruction, a segmentation process to label the different anatomical areas must be performed. The most common image modality employed in liver nowadays is contrast-enhanced CT. In CT images of the liver, the segmentation process is challenging since the tumours and surrounding organs present similar intensity values. Heinmann *et al.* [7, 8] and Campadelli *et al.* [9] provide surveys about different liver segmentation techniques. The methods included statistical shape models, atlas registration, level-sets, graph-cuts, and rule-based systems.

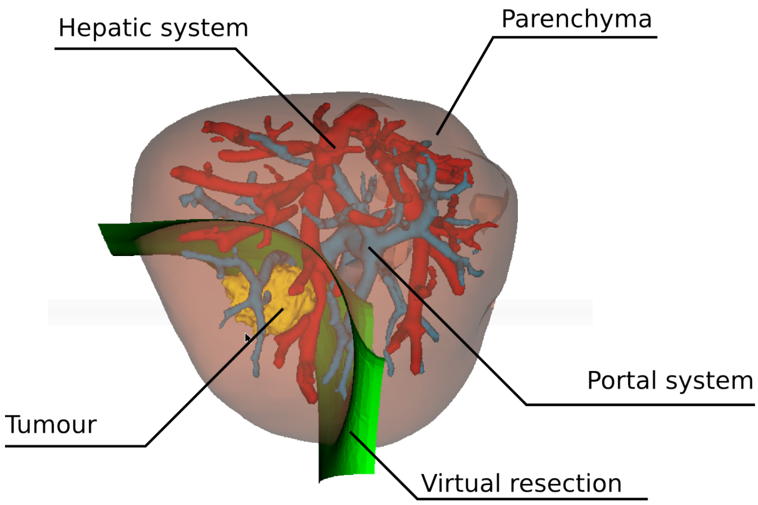


Figure 2: Geometric objects conforming a liver resection plan.

The goal of the planning is the definition of the *virtual resection* trying to minimize the risk for the patient, resecting the tumor safely while maximizing the remnant healthy functional tissue. Section 3.3.1 describes the techniques currently employed to calculate the *virtual resection*.

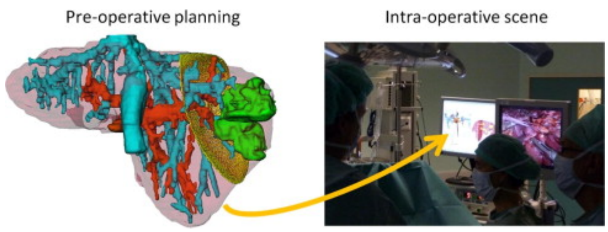
2.3 Navigation of Laparoscopic Liver Resection

Traditionally, laparoscopic liver surgery procedures has been guided by means of video captured from inside the patient's abdomen using a laparoscope. This information can be complemented by *ultrasound* (**US**) imaging and the use of *pre-operative* imaging like CT or MRI. Together with all this information, 3D models providing data about the geometry, resection plan and risk analysis, have been introduced [10, 11]. Though 3D models provide very valuable information, their use do not replace video technology and CT/MRI *pre-operative* imaging.

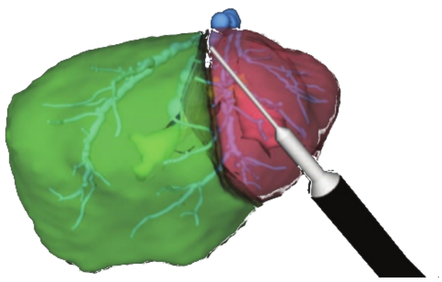
Navigation of 3D models during surgery consist of aligning the 3D model with the real organ so that the laparoscopist can establish a direct relationship between the virtual plan and the clinical reality. To facilitate this alignment, transformations such as rotations and translations can be applied to the 3D model.

More advanced navigation can be achieved by tracking the surgical tools and representing them in the virtual scene. To do this, registration between the virtual and the real organ must be performed, typically by either *landmark registration* or *surface registration*. In *landmark registration*, a set of points (usually less than 10) defined in the virtual model are matched to a set of points in the physical organ. On the other hand, *Surface registration* requires the acquisition of a more dense cloud of points to match the geometry of the real organ

Figure 3 shows navigation in liver surgical procedures both with and without the use of tracked tools.



(a) Navigation in surgery (extracted from [12]).



(b) Navigation with tool tracking (extracted from [13]).

Figure 3: Navigation in liver surgical procedures.

3 Research Proposal

Surgery is shifting to minimally invasive procedures. During the last two decades, these procedures have been a major area of research in both the medical and the computer science fields. Laparoscopic liver resection has been benefited by this research and the associated technological development. Areas like segmentation, planning, risk assessment and navigation still remain a challenge.

The research program hereby presented is concerned with 2 problems:

- **Calculation of the resection surface**
- **Organ Surface registration**

In the global picture of planning and navigation for laparoscopic liver resection procedures, these two problems belong to different stages, namely *planning* and *navigation* (Figure 4). Despite of this difference, solutions for both problems strongly rely on the use of geometric modeling methods.

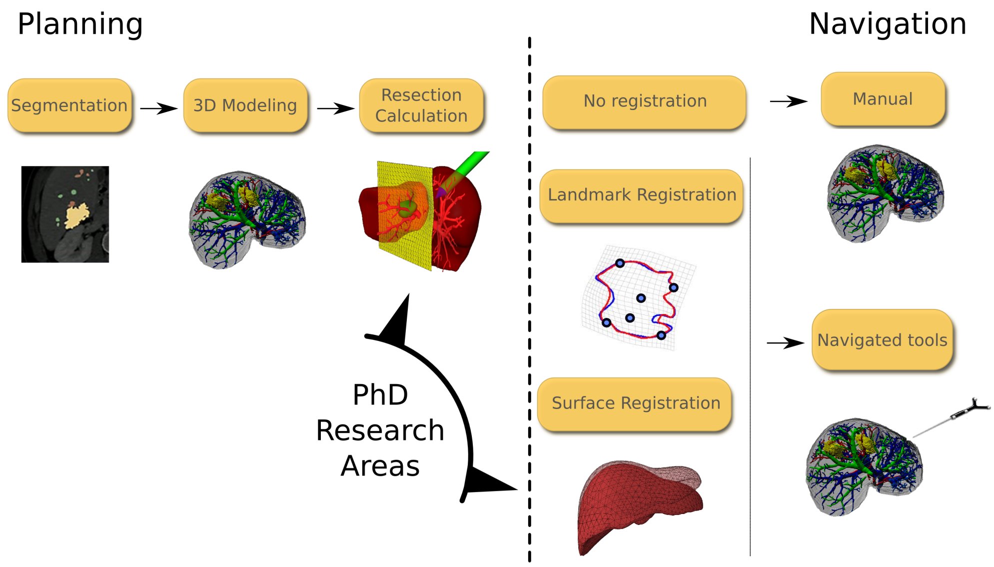


Figure 4: Planning and navigation in liver surgical procedures.

Along Section 3.1 we describe the state-of-the-art for both the **calculation of the resection surface** and **organ surface registration** problems in the context of laparoscopic liver resection. Thereafter, the research problems as well as the materials, methods and detailed work plan are described.

3.1 Brief State of the Art

Computer-assisted systems for liver surgical procedures have been an area of research for almost two decades. Some works highlight the benefits of using these systems in the clinical realm [11, 14, 15, 16, 17, 18]. Despite of the benefits, it is generally accepted that these systems are not ideal yet and therefore improvements are needed. As detailed below, **calculation of the resection surface** and **organ surface registration** are two of these areas that still remain a challenge.

Both the resection surface and the organ surface are related to surface reconstruction methods. In Table 1, we show a list of works related to liver surgical procedures together with the geometric methods employed by these, for the modeling of the organ and the calculation of the resection surface. There are a number of other publications related to liver surgical procedures using computer-assisted systems, however, they do not provide any detail on the underlying geometric methods. Though this research proposal is not directly concerned with the modeling of elements like *vessels* or *tumors*, it is interesting to keep those in mind since the introduction of new techniques for modeling of the *parenchyma* might also lead to interesting results for *vessels* and/or *tumours*.

Table 1: Reconstruction methods applied to liver surgery systems in the scientific literature.

Year	Publication	Parenchyma	Vessels	Tumour	Resection Surface
2013	Ruskó *et al.* [19]	N/A	N/A	N/A	Slice-drawing/B-Spline
2013	Khaleel *et al.* [20]	N/A	Poisson	N/A	N/A
2012	Drechsler *et al.* [21]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2012	Amber *et al.* [22]	Marching Cubes	N/A	N/A	N/A
2012	Foruzan *et al.* [23]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2011	Song *et al.* [24]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2010	Schwaiger *et al.* [25]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2010	Shevchenko *et al.* [26]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2010	Machucho-Cadena *et al.* [27]	N/A	N/A	CGA	N/A
2010	Lamata *et al.* [11]	Simplex Meshes	Simplex Meshes	Simplex Meshes	Deformable surface
2010	Demedts *et al.* [28]	N/A	N/A	N/A	Deformable surface
2010	Ai *et al.* [29]	Marching Cubes	N/A	N/A	N/A
2009	Song *et al.* [30]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2008	Lamata *et al.* [31]	Simplex Meshes	Simplex Meshes	Simplex Meshes	Deformable surface
2008	Lee *et al.* [32]	MPU	N/A	N/A	N/A
2008	Schenk *et al.* [15]	N/A	N/A	N/A	Deformable surface
2007	Schumann *et al.* [33]	N/A	Improved MPU	N/A	N/A
2007	Niculescu *et al.* [34]	Marching Cubes	N/A	N/A	N/A
2007	Bornik [35]	Simplex Meshes	Simplex Meshes	Simplex Meshes	Deformable surface
2006	Reiginger *et al.* [36]	Simplex Meshes [37]	Simplex Meshes	N/A	N/A
2005	Numminen *et al.* [38]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2005	Bornik *et al.* [39]	N/A	Simplex Meshes	N/A	N/A
2005	Reitinger [40]	Simplex Meshes	Simplex Meshes	Simplex Meshes	Deformable surface
2004	Konrad-verse *et al.* [41]	N/A	N/A	N/A	Deformable surface
2003	Doherty *et al.* [42]	Marching Cubes	Marching Cubes	Marching Cubes	N/A
2003	Preim *et al.* [43]	N/A	N/A	N/A	Slice-drawing
2001	Preim *et al.* [44]	N/A	N/A	N/A	Volume erasing
2000	Preim *et al.* [45]	Marching Cubes	Marching Cubes	Marching Cubes	N/A

3.1.1 Virtual Resection Calculation

The ability to specify virtual resections is a core function of many intervention planning systems. In difficult cases, the exploration of resection strategies directly supports the question of whether the resection is feasible at all as well as the specification of the resection strategy. The specification of a virtual resection can be used for a quantitative analysis with respect to the volume of the intended resection or the percentage of an organ which would be removed.

There are mainly five approaches to model virtual resections:

Volume sculpting in which volumetric data is modified by adding or removing certain geometric primitives. In traditional geometric modelling this is also known as constructive solid geometry.

Volume cutting where the user can cut through the data while the visualization is continously updated. This technique is often applied in connection with medical volume data. The interaction is inspired by real surgical procedures. For surgery simulations, this approach is often combined with haptic feedback devices.

Volume erasing by using scalable 3D shapes (*erasers*) which remove the tissue enclosed in the shape, like in Preim *et al.* [44]. The 2D visualization in this approach was only used to present the result of the virtual resection. However, the evaluation clearly showed that it was too difficult to specify resections precisely. For example, surgeons often plan their resections in relation to bifurcations of a vascular system. This means that the virtual resection facility should enable the surgeon to specify that a certain segment of a vascular system will be resected. The specification by erasing turned out to be too difficult to control for such a fine-grained specification.

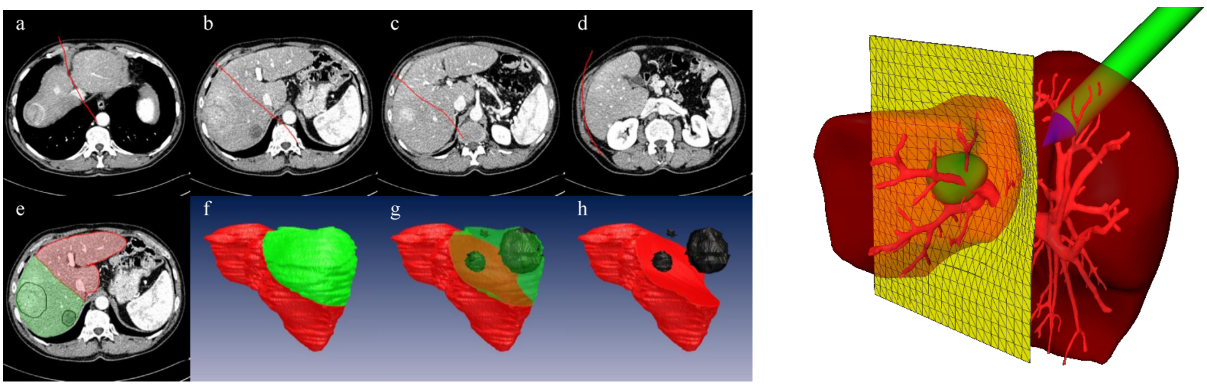
Drawing in 2D slices of the CT/MR volume where the user delineates individual parts of the resection in the 2D slices. The user draws lines on the 3D surface of the organ to initialize the virtual resection. From these lines, a first approximation of the cutting plane is generated. Then, the plane is deformed locally to match the lines drawn by the user. The cutting plane can be interactively modified to refine the virtual resection. Drawing in 2D slices (Figure 5.a) resembles the metaphor of the communication between surgeons and radiologists discussing a resection. Clearly, by drawing in slices a resection can be specified as precisely as desired. However, this process is time-consuming if the entire resection volume should be specified because often some 50-100 slices are involved [46]. The process can be strongly enhanced with interpolation methods like in Ruskó *et al.* [19]. Instead of drawing in all slices, the user might skip many slices in which the contour is computed by shape-based interpolation.

Using deformable resection surfaces which presents similarities with both *volume erasing* and *drawing on 2D slices*. The use of deformable surfaces (Figure 5.b) was first proposed by Konrad-Versel *et al.* [41]. That approach presents some similarities with the virtual resection based on erasing in the data (it includes 3D interaction) and some similarities with the virtual resections by drawing in the slices. The user should draw lines on the surface of an organ to initialize the virtual resection. Out of these lines, a mesh is generated that represents the initial cutting plane. The plane is deformed locally to fit the lines drawn by the user. This cutting plane can be interactively modified to refine the virtual resection.

Volume cutting and *volume sculpting* present an approach which is closer to surgical simulation and therefore would take too long for their practical application in the clinical environment. *Volume erasing* turns out to be difficult to control, specially while trying to specify fine-grained resections.

Drawing in 2D slices can be very time consuming though some authors presented resections drawing only on 3 to 5 slices. These authors do not present any evaluation or quality measurements which can relate this low interaction with good virtual resections. Potential problems to this latter approach are the loss of 3D awareness, since the interaction takes place in a 2D environment, and the difficulty to specify resections on slices where the tumours are not present (specially in highly curved resections).

In the scientific literature, the most common planning techniques are based on *deformable resection surfaces* (Table 1). Hansen *et al.* [47] points out that deformable surfaces are prone to error and consumes time in the clinical routine. In the same publication, the author barely describes the ideas towards automatic generation of resection surfaces, though no further report on such techniques has been found in the scientific literature.



(a) Drawing in 2D Slices (extracted from [19]).

(b) Deformable surface (extracted from [35]).

Figure 5: Surface calculation techniques.

3.1.2 Organ Surface Registration

Registration is an essential process in computer-assisted surgery systems. This process consists of aligning different coordinate systems together into a common coordinate system. Registration can broadly be classified into: *rigid registration* and *non-rigid registration*. Only rigid registration is employed in commercial systems nowadays [48].

Good reviews of medical image registration methods were published, earlier by Maintz *et al.* [49] and recently by Markelj *et al.* [50]. Though the authors focus on registration of medical images, its classification and some of the principles are of direct application to organ surface registration.

In relation to liver surgical procedures, registration methods were first applied to open surgery [51, 52, 53]. These methods employ laser-range scanners (**LRC**) as a *intra-operative* data modality. LRC are based on the acquisition of a dense 3D point by projecting a light beam on the surface of the organ and are know to provide precise results (less than 2 millimeters average error in phantom studies [52]), though organ deformation during surgery can increase the error. Some aspects of laparoscopic procedures are considered to be more challenging than their counterparts in open surgery, registration is not an exception. Very recently, Kingham *et al.* [54] proposes a protocol in which registration in laparoscopic surgery is performed by means of LRC, achieving an average error of 5 millimeters. Landmark registration has been employed earlier in Kleeman *et al.* [10] and vom Berg *et al.* [55], though it is generally accepted that surface registration is more accurate.

New sensing techniques such as 3D video acquired through stereo laparoscopes have been recently introduced in the surgical practice [56]. Structured light and time-of-flight are promising techniques but still are in an early research stage [57].

Regardless of the *intra-operative* modality employed, the method for obtaining rigid-body transformation parameters as in landmark registration is a relatively simple process described in Challis *et al.* [58]. On the other hand, surface registration is a challenging problem. Along the scientific literature, approaches based on *iterative closest point* (**ICP**) have been used to perform surface registration, like in Bouaziz *et al.* [59]. ICP has been used also recently to perform non-rigid registration on liver data [60]. Rohl *et al.* [61] employ 3D video for real-time reconstruction of surfaces with registration purposes, however, the authors focus on the surface reconstruction problem and do not address the registration problem.

The challenges associated with ICP-based methods are 1) missing data from 3D scanning and 2) sensitivity to outliers. As stated by Bouaziz *et al.* [59], most implementations of ICP try to address these problems by using heuristics to prune or reweight correspondences. However, these heuristics can be unreliable and in many cases, they require manual assistance.

3.2 Research Questions

The introduction of computer systems for planning and navigation of liver resection procedures has also introduced new challenges. Currently, both planning and navigation requires a significant amount of user interaction, making the process to be *time-consuming* and *error-prone*. Hence, there is a need for investigation of new techniques that reduces the user interaction and provide a more precise surgical guidance. This research proposal focuses on the two problems described below.

Resection Surface Calculation

- Objective measurements on surgical risk and outcome which can depict the optimality of a resection plan have to be investigated. These measurements are expected to be used by an algorithm to approximate an optimal resection plan.

- New methods for calculating the resection surface with reduced user interaction will be investigated. The question of whether an optimal resection can be automatically calculated based on the proposed methods will be also investigated.

Organ Surface Registration Using Intra-operative 3D Video

- There are different methods for the reconstruction of 3D surfaces from clouds of points. Their properties and whether they are suitable for liver reconstruction from *intra-operative* 3D video, specifially for registration purposes, is a fundamental question to address.

- Many reconstruction methods have not been employed for the reconstruction of liver from *pre-operative* CT/MRI data. Algorithms providing with desirable properties for registration will be explored and adapted.

- In connection with the two previous points, a method that can register the surface extracted from *intra-operative* 3D video and the surface reconstructed from *pre-operative* CT/MRI need to be investigated. There are a number of registration methods based on ICP. Whether one of these methods can be adapted to the particularities of our problem, will be studied.

3.3 Materials and Methods

3.3.1 Resection Surface Calculation

Resection surface calculation as performed nowadays present some problems. This research will focus on reducing the derived problems from the *Drawing in 2D slices* and the *Deformable surface* approaches, which are the two most commonly used in the literature. Both of these methods rely on the user to define partially/completely the resection surface.

User interaction can be reduced by employing optimization techniques to find those 3D points lying in an optimal resection surface and then reconstructing the surface that best fits the point set. I intend to research on the application of optimization techniques, with special attention to evolutive algorithms, which have proven to be powerful optimizers.

Evolutive algorithms encode multiple solutions of a problem in individuals of a population that evolves over time employing bio-inspired mechanisms (i.e, mutation, selection, crossover). Particularly interesting to our problem might be a not so studied branch of the evolutive algorithms called *Parisian evolution* [62]. In *Parisian evolution* the solution to the problem is not encoded in one single individual, but in a whole population of individuals [63, 64].

After the optimal set of points is found, a surface reconstruction algorithm can be applied. Bolitho [65] reviews the main techniques to reconstruct surfaces from set of points.

One important aspect in any optimization method is the optimization criteria. Scientific publications ([21, 25, 13, 66, 67]) on planning and risk analysis reveal some of the objective criteria that can be employed:

- Minimization of resected volume.
- Maximization of functional remnant volume.
- Curvature of the resection.
- Guaranteeing of the safety margin.
- Distance of anatomical elements (vessels, tumors) to the resection surface.

Demedts *et al.* [28] propose a resection score baed on:

- Remnant volume in milliliters.
- Safety margin around tumours in millimiters.
- Supplied volume of the remnant liver in %.
- Completely perfused remnant liver in %.
- Resection area in squared centimeters.
- Curvature of the resection surface in degree.

3.3.2 Organ Surface Registration Using Intra-operative 3D Video

Recently, 3D video ha[illegible] introduced in the clinical routine for laparoscopic liver resection. Apart from providing the laparoscopists with a mean to guide a resection with depth perception, stereo video can be used to extract the 3D structure of an organ *intra-operatively*. Rohl *et al.* [61] recently proposed a method to extract surface information from stereo video for registration purpose[illegible]wever, the authors only obtain the surface without addressing the registration problem.

In Table 1, one can observe that most of the reconstructions of the *parenchyma* have been performed by using *marching cubes* [68], which, for instance, is known to produce *staircase* artifacts on images presenting anisotropic resolution (different resolutions in different axis). No work has been found that relate the reconstruction method and its properties with the registration process.

In order to address the registration problem, I intend to consider not only which ICP-based method can be employed, but also which reconstruction methods are appropriated for both the *intra-operative* surface from stereo-video and *pre-operative* surface from CT/MRI. Methods reviewed by Bolitho in [65] will be explored to find the most adequate for registration purposes.

3.3.3 Clinical Integration and Validation

One of the aims of this research is applying the methods previously described to improve the surgical practice and generate clinical knowledge. To achieve this, the methods will be integrated into a prototype that can be used clinically (please, read Section 3.3.4). A prototype of the planning and navigation software has been partially integrated in the clinical setup at *The Intervention Centre (Oslo University Hospital)* and will be completed with the methods developed during this research program.

In order to get clinical feedback, the development will be accompanied by regular meetings with liver surgeons where the progress will be presented and discussed.

Along with the technical evaluation of the methods, evaluation studies, similar to the presented by Hansen *et al.* [18, 66] and Lamata *et al.* [11] will be performed to assess the techniques and generate clinical knowledge.

3.3.4 Ethical considerations

It is of great importance to remark that the introduction of these methods in the clinical setup, under any circumstances, **does not** replace the state-of-art technology used in the clinical routine (*intra-operative* US, *intra-operative* videoscopy and *pre-operative* CT/MRI). These methods only present additional information that can only be an advantage for the surgical practice.

To ensure that the additional information presented is complete, correct and faithful, we establish a strict protocol during planning, in which the two laparoscopic surgeons who will perform the surgical procedure review this information and agree on its use. The use of state-of-art technology in clinical practice will always prevail over the new information presented to the laparoscopists.

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.

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*.

3.4 Research Plan

In the previous section, the materials and methods that will be employed during the research process has been presented. 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 6.

WP1 - PhD Management The aim of this package is to establish the basis for the research program and compile and prepare the scientific outcome for the PhD dissertation.

T1.1 **Research Plan** which will be delivered within the first 3 month of the research to the admission board at *Gjøvik University College* for its approval.

T1.2 **Environment Preparation** this task is concerned with the preparation of the research environment, both technically and clinically. As previously mentioned, a prototype of the navigation/planning software is available at The Intervention Centre. This task will complete the setup by:

- Integrating optical tracking stream in the software prototype.

- Integrating calibration routines for the surgical tools.
- Integrating simple rigid registration routines for *intra-operative* navigation.

It is worth mentioning that all the technologies are available as well as their implementations. This package will only integrate the technologies into the software for navigation/planning, no new algorithms will be researched or developed in this task.

T1.3 **Literature Review** the literature review will provide the basis to support the research process on. The topics to be reviewed are:

- Liver resection planning systems.
- Liver resection navigation systems.
- Surface reconstruction methods (starting from [65]).
- Optimization methods and evolutive algorithms.
- ICP methods for surface registratin.

T1.4 **Publications** this task is present all along the research process. This task consist of preparing all the scientific material and generate scientific publications. A list of candidate journals and conferences is shown in Table 2.

Table 2: List of candidate journals and conferences.

Journals
IEEE Transactions on Medical Imaging
Medical Image Analysis
Computerized Medical Imaging and Graphics
The International Journal of Medical Robotics and Computer Assisted Surgery
Computer Methods and Programs in Biomedicine
Computers in Biology and Medicine
Journal of Gastrointestinal Surgery
Surgical Endoscopy
Conferences
IEEE Engineering in Medicine and Biology Society
Medical Imaging Computing and Computer Assisted Interventions
Computer Assisted Radiology and Surgery
Information Processing in Computer-Assisted Interventions
SPIE Medical Imaging
International Conference on Pattern Recognition

T1.5 **Courses** as part of the PhD program, the courses proposed on Table 3 will be undertaken.

Table 3: List of courses.

Code	Course	Institution	ECTS credits	Period
IMT5281	Advanced course on video processing	Gjøvik University College	5	Autumn 2013
MATINF9170	Spline methods	University of Oslo	10	Spring 2014
MNSES9100	Science, ethics and society	University of Oslo	5	Autumn 2014
STK4900	Statistical methods and applications	University of Oslo	10	Spring 2015

WP2 - Resection Surface This work package is concerned to one of the main research topics, namely *Resection Surface Calculation*. The aim is to provide surgeons with new computational methods able to calculate an optimal resection surface with minimal user interaction.

T2.1 **Manual calculation of resection** the result of this task is the implementation of a method that resembles some of the characteristics of the state-of-art methods. The idea is that, regardless of the amount of user interaction, the surgeon can perform resection plans in a very precise way. This will enable the obtention of data that can be considered as a ground truth, thus providing a benchmark for the evaluation of the new methods.

T2.2 **Improved calculation of resection** this task will explore the application of optimization techniques, with special attention to evolutive algorithms for the problem of optimizing the resection surface. The objective is the reduction of user interaction to the minimum, though at the moment it is difficult to state that completely automatic approaches are feasible. The criteria and methods to be employed are described in the previous section.

WP3 - Organ Registration This work package addresses the second main research topic, namely *Organ Surface Registration using 3D intra-operative video*. This work package will study algorithms for:

- Organ surface reconstruction from *pre-operative* CT/MRI.
- Organ surface reconstruction from *intra-operative* laparoscopic 3D video.
- ICP-based registration.

The idea is obtaining a combination of these algorithms that can achieve the best registration results.

T3.1 **Organ Reconstruction from 3D Video** this task will take place in collaboration with *University of Paris*. The stereo video from laparoscopic surgery will be analyzed to recover the 3D structure of the liver surface. I will pay special attention to the correct reconstruction of a surface that presents desirable properties for its registration. Modification of existing reconstruction methods might be considered if during the research, a clear benefit is found.

T3.2 **Organ Reconstruction from CT/MRI** this task will explore reconstruction methods which have not been applied before for liver modeling. The aim is to find which methods provide surfaces with desirable properties for its registration. Modification of existing reconstruction methods might be considered if during the research, a clear benefit is found.

T3.3 **ICP-based registration** this task will explore ICP-based methods to accomplish the registration of surfaces reconstructed from *pre-operative* CT/MRI and surfaces reconstructed from 3D video. This task will take place at the same time as **T3.1** and **T3.2**.

WP4 - Clinical The clinical character of this research proposal makes necessary the allocation of this work package. The aim of the package is to provide the means for the technical research to reach the clinical environment. This work package will be present all along the research process in a cycle of *integration - clinical feedback - data gathering*. The result of the following tasks is expected to be published in journal/conferences of a more clinical nature.

T4.1 **Clinical Integration** this task consists of integrating the methods developed during the extent of the research into the planning and navigation software at The Intervention Centre. This software, which is based in open-source technologies, is highly extensible. This technology integration enables to gather data which may lead to publications in clinical journals/conferences.

T4.2 **Clinical Validation** technical validation of the researched methods would not be very much of use without a validation of its clinical applicability and usefulness. This task has two objectives:

- Gathering of clinical feedback that can guide the research process towards useful methods.
- Gathering clinical data that helps test, research and validate the proposed methods.

Patient data 3D reconstructions, resection plans and questionnaires to the clinical team will be obtained from the beginning of the research program.

3.4.1 Funding Plan

This PhD program is a formal collaboration between *The Intervention Centre (Oslo University Hospital)* and *Gjøvik University College*. The PhD fellow will be employed the first 12 months of the program at *The Intervention Centre*. The remaining 24 months the employer of the PhD fellow will be *Gjøvik University College*.

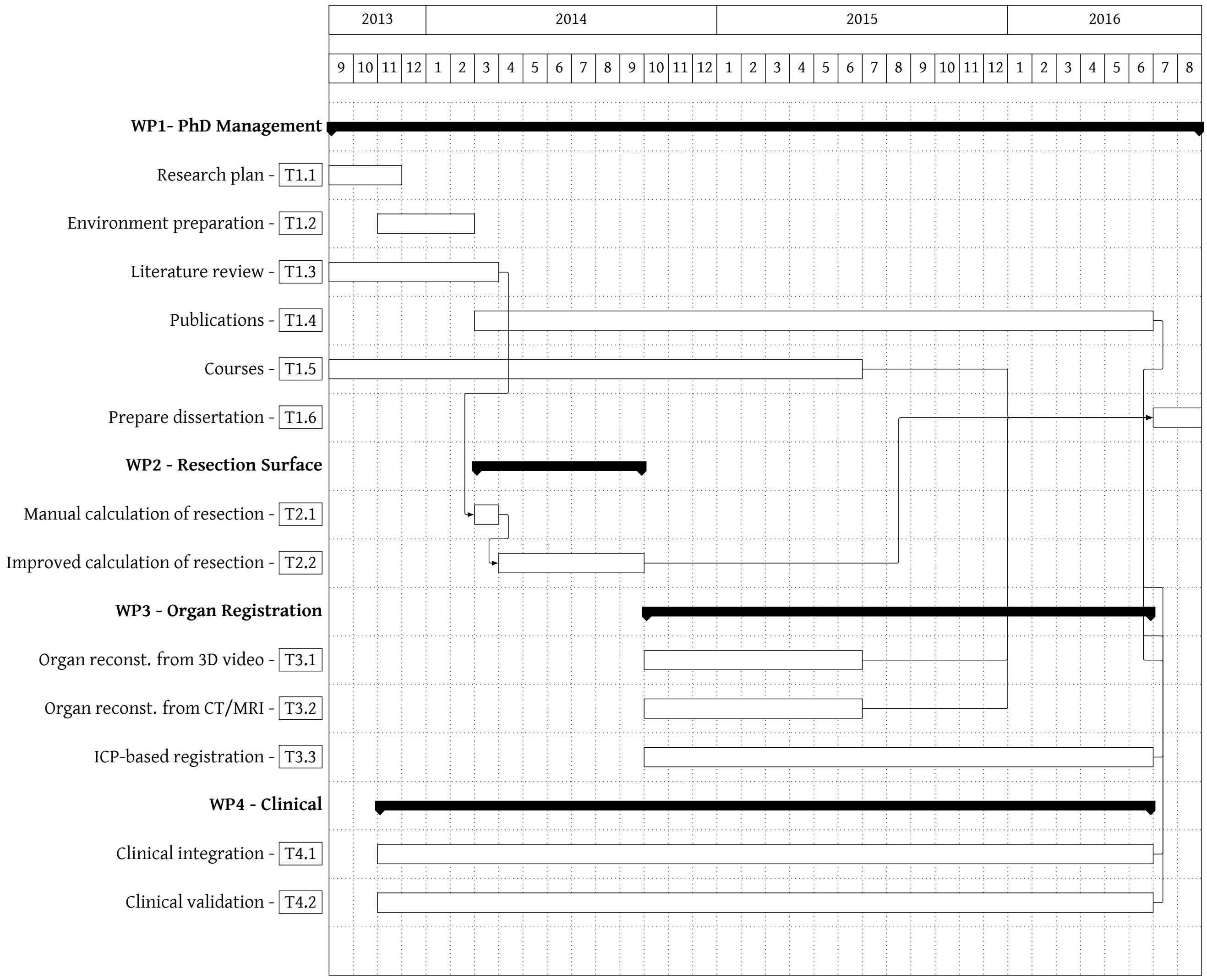


Figure 6: Gantt chart for the research project.

3.4.2 Statement of Required Infrastructure

The medical equipment required to develop this research plan will be provided by *The Intervention Centre*. Any other equipment needed during the research program will be financed either by *The Intervention Centre* or *Gjøvik University College* upon agreement.

3.4.3 Statement of Supervision

This research program will be supervised by:

- Prof. Ole Jakob Elle, PhD. The Intervention Centre, Oslo University Hospital. (first supervisor).
- Prof. Faouzi Alaya Cheikh, PhD. Gjøvik University College.
- Prof. Azeddine Beghdadi, PhD. University of Paris.
- Prof. Bjørn Edwin, MD. PhD. The Intervention Centre, Oslo University Hospital.

3.4.4 Work location and mobility plan

The core work location of the PhD fellow will be *The Intervention Centre*, *Oslo University Hospital* (Rikshospitalet), where the medical equipment and clinical team are also located. Bi-weekly (two every month) meetings in *Gjøvik University College* will be established to follow the research process. The PhD fellow will additionally participate and contribute to the research environment in *Gjøvik University College* according to the activities organized in the frame of the Hypercept project and The Norwegian Color Lab.

Mobility to Paris is also expected upon agreement and under the collaboration frame of the three institutions (*The Intervention Centre*, *Gjøvik University College* and *University of Paris*).

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