DEVELOPMENT OF A VISION SYSTEM FOR SHIP HULL INSPECTION

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by

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LIST OF SYMBOLS

z	Vertical
y	Horizontal
Ψ(x)	Roll
ɵ(y)	Pitch
Φ(z)	Yaw
x	optical axis
$[x,y,z]^T$	ROV position relative to the earth-fixed reference frame
$[ψ,ɵ,φ]^T$	ROV roll, pitch and yaw angles relative to the earth-fixed reference frame
$[u,v,w]^T$	ROV linear speed (surge, sway, heave) relative to the vehicle-fixed reference frame
$[p,q,r]^T$	ROV angular speed (roll, pitch and yaw rates) relative to the vehicle fixed reference frame
q	Direction
r	position
DR	Laser distance (right beam)
DL	Laser distance (left beam)
PR	Pixel position (right beam)
PL	Pixel position (left beam)
α, β	the angle between the object surface and the vehicle orientation
m	Meters (unit)
cm	Centimeter (unit)
P max	Pixel coordinate with the highest intensity
xm	Centroid coordinate of X
ym	Centroid coordinate of Y
r	Radius mean value
px	Pixel coordinates of X
py	Pixel coordinates of Y
k	Extinction coefficient of the laser in turbid water
Io	Incident energy
i	Transmission distance
D	Actual surface distance from the camera
rx	The highest intensity on the right (X-axis)
lx	The highest intensity on the left (X-axis)
ty	The highest intensity on the top (Y-axis)
by	The highest intensity on the bottom (Y-axis)

d	Distance between the image field and the laser pointer
L1	Laser 1 projection point
L2	Laser 2 projection point
L3	Laser 3 projection point
dLA	Distance between the Laser 1 projection point and the lens
dLB	Distance between the Laser 2 projection point and the lens
dLC	Distance between the Laser 3 projection point and the lens
La	Distance between the L1 and the center of image in camera FOV
Lb	Distance between the L2 and the center of image in camera FOV
La	Distance between the L3 and the center of image in camera FOV
CxLa,CyLa	Centroid of L1 in camera FOV
CxLb,CyLb	Centroid of L2 in camera FOV
CxLc,CyLc	Centroid of L3 in camera FOV
CenterX, CenterY	Center Coordinate in camera FOV
Px1,Py1	Coordinate of the object in camera FOV

LIST OF ABBREVIATION

ROV	Remotely Operated Vehicle
CCD	Charge Coupled Devices
TV	Television Monitor
NDT	Non destructive test
MFD	Marine Facilities Division
DIDSON	Dual Frequency Identification Sonar
DOF	Degree of Freedom
AUV	Autonomous Underwater Vehicle
2 D	Two Dimensional
2 ½ D	Two Half Dimensional
PPM	Parts per million
ROI	Region of interest
FOV	Field of view
ER	Error Ratio
DC	Direct current
CPU	Central Processing Unit
TTL	Transistor-transistor logic
SPSS	Statistical Package for the Social Sciences
OpenCV	Open Source Computer Vision Library
JPEG	Joint Photographic Experts Group
DIVX	Digital Video Express (usage-sensitive DVD-ROM format)
USB	Universal Serial Bus
PC	Personal Computer
RGB	Red Green Blue
mW	Milliwatt
nM	Nanometers
PID	Proportional-Integral-Derivative
MS-DOS	Microsoft Disk Operating System
SNR	Signal to noise ratio
FOV	Field Of View

PEMBANGUNAN SEBUAH SISTEM PENGLIHATAN BAGI PEMERIKSAAN BADAN KAPAL

ABSTRAK

Penyelidikan ini memperkenalkan strategi pengawalan untuk memperbaiki prestasi pemeriksaan visual badan kapal dengan menggunakan kenderaan dalam air. Kaedah yang dicadangkan bertujuan untuk membangunkan sebuah sistem yang secara visualnya sentiasa kekal selari pada permukaan badan kapal. Terdapat empat komponen utama di dalam system ini iaitu kamera, penunjuk laser, platform pan & menyenget dan platform Cartesian. Kamera dan penunjuk laser adalah berkedudukan tetap pada posisi yang telah ditentukan. Sistem ini menyepadukan kaedah penjejakan pancaran laser dan kaedah navigasi bagi kenderaan di bawah air. Pada mulanya, kecerahan laser di jejaki dengan menggunakan kaedah "Region of Interest (ROI)" secara anggaran dinamik. Kemudian, proses penyiaran sifat digunakan bagi mengenalpasti kedudukan setiap laser pada satah visual diikuti dengan kiraan jarak anggaran di antara kamera dan permukaan objek. Kaedah asal penyegitigaan laser untuk mengukur jarak telah diubahsuai untuk kegunaan system ini. Sistem kawalan suap balik telah dibangunkan untuk mengenalpasti kedudukan kamera dan permukaan objek. Algoritma untuk sistem kawalan tersebut telah dibangunkan dengan menggunkan Intel Open CV dan Visual C++. Platform Cartesian telah digunakan untuk mengaplikasikan sistem ini. Beberapa eksperimen menggunakan permukaan badan kapal yang dimodelkan telah dilaksanakan. Sistem jejakan ini boleh melakukan pergerakan secara mengufuk dan menegak pada jarak 17cm hingga 100cm daripada kamera kepada permukaan objek dan bertindakbalas dalam masa 1-3s dari sebarang permukaan kepada permukaan yang selari di permukaan yang rata dan 2-4s ke atas permukaan yang melengkung. Kesimpulannya, sistem yang diperkenalkan ini terbukti akan keupayaannya dan didapati amat praktikal dan mempunyai potensi untuk kegunaan teknologi pemeriksaan badan kapal di bawah air.

DEVELOPMENT OF A VISION SYSTEM FOR SHIP HULL INSPECTION

ABSTRACT

This work introduces a strategy to improve the performance of visual ship hull inspection using a Remotely-Operated Vehicle (ROV) as its underwater vehicle platform. The proposed method is aimed at developing a system that will maintain the camera viewing angle parallel to the ship hull surface. This system consists of four main units, namely, camera, laser pointers, pan-tilt platform and Cartesian platform. The position of the camera and the laser pointers are fixed. The system integrates laser beam tracking and underwater vehicle guidance technique. Initially, the region of interest (ROI), based on laser intensity input, is tracked with dynamic ROI estimation technique. Then, the feature extraction process will acquire the position of each laser points in the frames, and calculate the distance of the laser source and the surface. The range measurement was performed using the modified laser triangulation technique. This application focuses on binary images with extension of gray level concept. A closed-loop control system has been developed to classify the camera positions. An algorithm for overall system control has also been developed, using Intel Open CV and Visual C++. This system has been applied to the Cartesian platform. Several experiments using scaled-down ship hull structure are carried out. The test results are given and analyze to show its significant result The tracking system is able to perform horizontal and vertical slices within the range of 17 cm and 100 cm from the camera to the hull surface and the respond time is about 1 – 3s from the arbitrary surface to parallel surface on flat surface and 2 – 4s on curve surface. . In short, the system is found to be very practical and have great potential usefulness for ship hull inspection technology.

CHAPTER ONE
INTRODUCTION

1.0 Introduction

Remotely operated vehicle (ROV) is a machine powered by electric current. The current and data link are transported by wires in a long cable, called umbilical, which connects the underwater robot with its power source. ROV is directly controlled by a pilot above the water surface. A camera mounted on the ROV enables the pilot to see what the robot is countering underwater and thus effectively navigate and control the robot's movements (Harry et. al., 1997). ROV can be effectively used for underwater applications, such as, drill, construction support and pipeline. Among the benefits of using these vehicles are; human safety, reduction in mission cost, and improved accuracy for repetitive and routine tasks. As the area of underwater robotics matures, ROV's are also important in ship hull inspection process (Lynn et al., 1999; Cadiou et. al., 1998; Amat et. al., 1999). The main difficulty of ship hull inspection is the complex shape structure, such as the bowl (Figure 1), especially at the front structure and thruster engine area (David et. al., 2003). New sensors or techniques to inspect difficult access areas are needed.

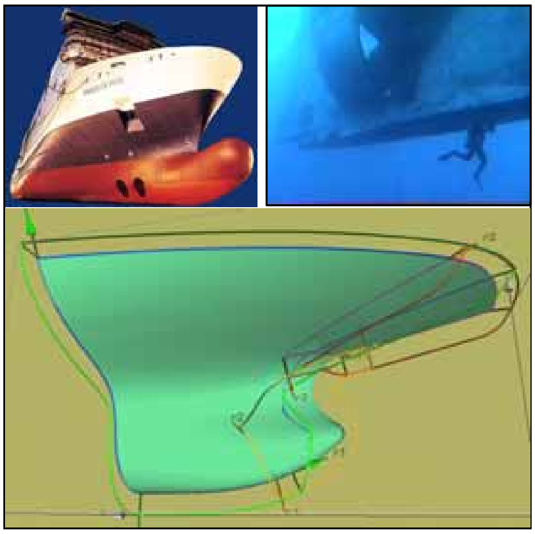

Figure 1.1 Example of a Ship Hull

Another related issues reported by the International Federation of Robotics (IFR) in cooperation with the United Nations Economic Commission for Europe (UNECE), the underwater robotics system is highly in demand (World Robotics, 2005). With 5,320 units, underwater systems accounted for 21% of the total number of service robots for professional use installed until the end of 2004. The most expensive robots are underwater systems (from $300,000 to more than $1,000,000). There was a growing numbers of underwater robotics vehicles were installed all over the world. The results from this should be applied to innovation of existing underwater vehicles which the main concerns are specifically to enhance and to upgrade its capabilities.

1.1 Ship Hull Inspection with an ROV

The attending inspector is generally limited to view the television (TV) monitor and video tapes, talking with the diver, observing (nondestructive testing) NDT procedures, reviewing any still photos, and reading the diver's survey report. The TV monitor should be located close to the diving supervisor's position to facilitate simultaneous viewing of the TV monitor and communication with the diver.

The diver's visual findings and commentary can be very beneficial. A knowledgeable inspection diver can provide greatly enhancing detail and description to the TV monitor. For example, wiping off sea growth to clear a picture of the weld or carrying a short ruler or a marked diving knife to give dimensions can be helpful to topside viewers. On the other hand, the camera used by the diver provides a small field of view. The view can be affected by water clarity, the diver's breathing bubbles, the diver's motion and speed of advance, glare from the diver's light as well as the amount of available light, etc. The diver's comments on the overall condition of the hull regarding sea growth, damages, and the coating system may prove to be helpful, but the inspector will maintain control of the inspection by requiring the diver to proceed at such a pace so that there is good visual acuity of the section of the hull being photographed. The inspector may also have to direct the diver to adjust the attitude of the camera to reduce glare or to bring an item more into focus.

Practically, the most important process in underwater ship hull inspection is visual monitoring. The owner should provide a copy of the audiovisual tape and the written report by a diving company. Advantages and limitations of using underwater robot for ship hull inspection are discussed as follows.

A. Advantages:

Unmanned underwater video systems allow inspection of underwater structures at greater depths and for longer time durations than do conventional diver systems. In addition, underwater video systems can perform repeated inspection dives at greater depths without sacrificing the quality of each inspection dive.

B. Limitations:

Remotely operated underwater video systems (both manned and unmanned) that function independently of divers do not possess the maneuverability offered by conventional divers. Therefore, care should be exercised when an ROV is directed into areas of restricted space relative to the size of the ROV. Carelessness in such a situation could result in the ROV becoming entangled or even possibly lost. Even though some ROV include an extension arm-type attachment for grasping some items, the ability to manipulate these items is usually restricted. Finally, the umbilical limits excursion distance of ROV.

Ship hulls are built in many shapes and size. Some are flat surfaces while others are curved, but most ship hull has one thing in common- they need regular inspection either on-site or in the dry dock (Harris et al., 1999; Miller, 1996; Fiala et al., 1996). Inspections are performed by sending divers or ROVs into the water surrounding the ship. More inspections are being done in water because the external hull is more accessible (Nicinski, 1983). Nowadays a lot of ROV and Autonomous

Underwater Vehicles (AUV) have been used to perform underwater ship hull inspection which was previously conducted by an expert diver. In order to avoid dry docking option, or to pre-plan the docking work package, it is desirable to perform a comprehensive underwater survey of the hull prior entering the dry dock (Carvalhoa et al., 2003).

1.2 Objective of Research

The main objective of this research is to develop an efficient ship hull inspection system using a Remotely-Operated Vehicle (ROV) as its underwater vehicle platform. The Inspection will be based on visual input from camera on a pan and tilt platform. There are several goals has been identified in order to achieve the main objective;

- To develop a visual inspection system for dynamic and uncertain environments that is flexible and easy to use. The system is able to positioned itself in reference to a surface with minimum supervision by the operator.
- To build the real time image processing and controller that deals with the physical control of the inspection system, so that the vehicle is able to perform necessary motion during the operation. This task requires the inspection system to track a particular area on the surface and positioned its viewing angle always parallel to the surface.
- The system is able to measure a particular object dimensions. This additional feature is purposely to extend the usage of the laser device itself.

Supporting processes required in achieving the above objective and goals are:

- To study the usage of an ROV for underwater inspection especially on ship hull inspection, including the main challenge and other related technologies.
- To study any related issues regarding control and guidance techniques for underwater vehicles.

- To study the usage of a laser for underwater application including; the characteristic of laser light over the undersea turbidity, and feature extraction techniques.
- To learn how to realize the design into a working prototype. This process includes simulating the design with computer aided design tool (*Solidworks*™).
- To develop a program with C programming command lines, and to explore any other software that is relevant to image processing development and calibration analysis.

1.3 Scope of the Research

This research will focus on one aspect of underwater hull inspection, the monitoring of hull structure with vision-based inspection system. Due to time constraints, this research will not cover in detail the validations and proofs of concept of using the inspection system in actual underwater environment. Cartesian platform has been used to replace an ROV. However, the main concept and constraints have been studied in order to visualize the situation. Modeling and predicting laser beam performance for underwater application can be categorized into few aspects; types of laser, underwater penetration characteristic, turbidity effect, back scattering effect, peak detection algorithm and polarization filtering. No consideration will be made to external underwater disturbance to the performance of the developed inspection system. The ship hull is assumed to be stationary.

1.4 Organization of Thesis

This chapter presented the overview information about ROV technology, ship hull inspection process, underwater inspection techniques and the motivation for the research effort. The main objective of this research is also presented.

In chapter two, the previous research and existing problems that relates to the ship hull inspection application is presented. An overview of the underwater laser image processing, control and guidance techniques are also discussed.

Chapter three discusses the theoretical basis for the research. It includes the system design, underwater laser triangulation, laser scaling system, adaptive region of interest estimation and centroid searching, parallel surface tracking, object locking and performance criteria.

Chapter four presents the method and implementation for the whole project. This includes the designing stage, research approach, parameters, software and hardware development, control architecture, algorithms, programming. A prototype of ship hull surface is also presented.

Chapter five outlines the experimental results obtained from the study. This chapter report on the results obtained during the test explained in chapter three and four respectively.

Finally, chapter six concludes the works of this research. This chapter also summarizes the limitations of the system and several suggestions for further works.

Appendices in this thesis comprises of the hardware and software specification and Visual C++ programming.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

The need for inspection of ship's hull for maintenance and damage is becoming increasingly prevalent. This task is presently performed by divers or a remotely operated vehicle (ROV). Both methods require significant personal and deck support equipment. Ship hulls, as well as bridges, port dock pilings, dams, and various underwater structures need to be inspected for periodic maintenance and repair. ROVs are suitable platforms for the development of an automated inspection system, but they require integration with appropriate sensor technologies (Negahdaripour et al., 2005; Vaganay et al. , 2005; Lynn, 1999; Nicinski, 1983).

Review of a few related topics which are considerably important factors to develop this system are presented in order to fulfill the design requirements. Four topic are discussed, i.e. ROV's and underwater inspection technologies, control and guidance techniques for underwater vehicles, underwater inspection technologies, and underwater laser triangulation techniques. The basic concepts are described and general comparisons are made on each topic.

2.1 ROV's and underwater inspection technologies

According to Canadian Shipping Act (2004), Japanese Ship Safety Law (2004), and US Coast Guard (2004), at least once every three years, the Marine Facilities Division shall carry an examination of each marine terminal to determine whether the structural integrity of the terminal, the oil transfer operations system and the safety equipment are designed and being maintained in a safe working condition. This law and regulation are to ensure that the seaworthiness of vessels and to protect lives. The objective of the inspection is not only to document and assess the criticality of deficiencies, but also to enhance reliability, safety and structural integrity of the terminal and its operation. The inspection is to be carried out by a qualified technician with adequate knowledge of hull structure inspection under the surveillance of a surveyor. The surveyor shall be satisfied with the method of live pictorial representation and the method of positioning of the technician on the structure (Kelly, 1999)

Underwater hull inspection involves the examination of the exterior underwater hull and components to determine the condition and needs for maintenance, repair and routine inspection. Underwater hull inspection can only be done by a qualified divers or an ROV. The inspection report must includes, general examination of the underwater hull plating, detailed examination of all hull welds, propellers, tail shafts, rudders, hull appurtenances, thickness gauging results, bearing clearances, a copy of the audio and video recordings, sea chests condition, and remove and inspect all sea valves. The Marine Inspector will evaluate the hull examination report and grant a credit hull exam if satisfied with the condition of the vessel. If approved the ship owner may receive a credit hull exam up to 36 months (with divers) and 60 months (with ROV) (US Coast Guard, 2004).

2.1.1 The need of an ROV for inspection

The important of ship hull inspection with an ROV has been mentioned before in previous chapter, in section 1.1. Among the ROVs used for this purpose can be found widely on the web, for examples;

- SubNet Services Ltd (Norwich), http://www.subnetservices.com/
- VideoRay LLC (USA), http://www.videoray.com/
- Pro-Dive Marine Services (Canada), http://www.prodive.ca/rov_services.htm
- Navigation Eng. Services Ltd, (UK) http://www.underwaterinspection.co.uk/
- Nova Ray, Inc. (USA), http://www.novaray.com/

All these ROVs are not only focus for ship hull inspection. Other services that can be done by an ROV are for instance; diver monitoring, drill rig support, subsea intervention, aquaculture facility inspection, dam inspection, salvage operations, under-ice survey and operations and police and rescue squad search and recovery operation.

Generally, underwater inspections method can be classified into four types; CCTV, photographic, Non-destructive test (NDT) and diver physical inspection. An underwater inspection is not just to record the video and save the data; it is an activity where the inspector probes and searches for signs, which may lead to future problems or any other possible damage and threat. In order to save the cost and minimize the loss time while performing ship hull inspection, ROV used as alternative. According to Lynn (2000), the ROV-based hull surveys can collect all the necessary information within a short period of time on the hull systems and allowing the US Navy to refine their work packages far ahead of the dry-docking. The US Navy spends about $300M/year to dry-dock ships, of which $80M is for paint removal and replacement.

However this procedure required a supervision of expertise. The ROV operator and the expertise will make decision base on what they observed and data measured.

But the visual data is not 100% accurate especially on the extreme curve surface. ROV cannot maintain its static position because of the underwater condition. Inconsistency in ROV's movement and the difficulty of ROV's operator to guide and control the camera at the same time resulted in the visual inspection error. Due to these factors, relative tracking control to perform XY positioning maneuver must be done. This feature may guide the ROV so that the vehicle is always perpendicular or relative to the ship hull surface.

2.1.2 Visual monitoring

In general, the underwater ship hull inspection technique can be classified into two; visual (using camera/sonar or human eye) and non-visual (using NDT or human touch). Both techniques are carried out by an expert diver or an ROV. This thesis intensively explores the visual monitoring improvement which will indirectly improve the NDT measurement as well. In another word, if the ROV can maintain its static position with respect to the ship hull, the NDT devices also could get advantage of it. ROV should provide a high quality of video and data measured of the hull and acquires a more complete picture of corrosion, coating condition, structural defects and hull form anomalies that simply are not available with traditional method (Harris et al., 1999).

Examples of research efforts conducted which are similar to the one covered by this thesis are given. Firstly, a hull-based relative tracking and control system which is primarily based on a Doppler Velocity Log (DVL), developed by Vaganay et al. (2005). In this approach, a 1200 kHz DVL, mounted on a tilt actuator, is used to control the Hovering Autonomous Underwater Vehicle (HAUV's) distance and bearing with respect to the hull and to keep track of its path as it travels along the hull by integration of the relative velocity. The Dual Frequency Identification Sonar (DIDSON) is mounted on its own tilt actuator which allows the vehicle to point it at the desired grazing angle with respect to the hull for good imaging. Figure 2.1 shows the positions of the HAUV, DVL beams and DIDSON beam while performing horizontal and vertical slices

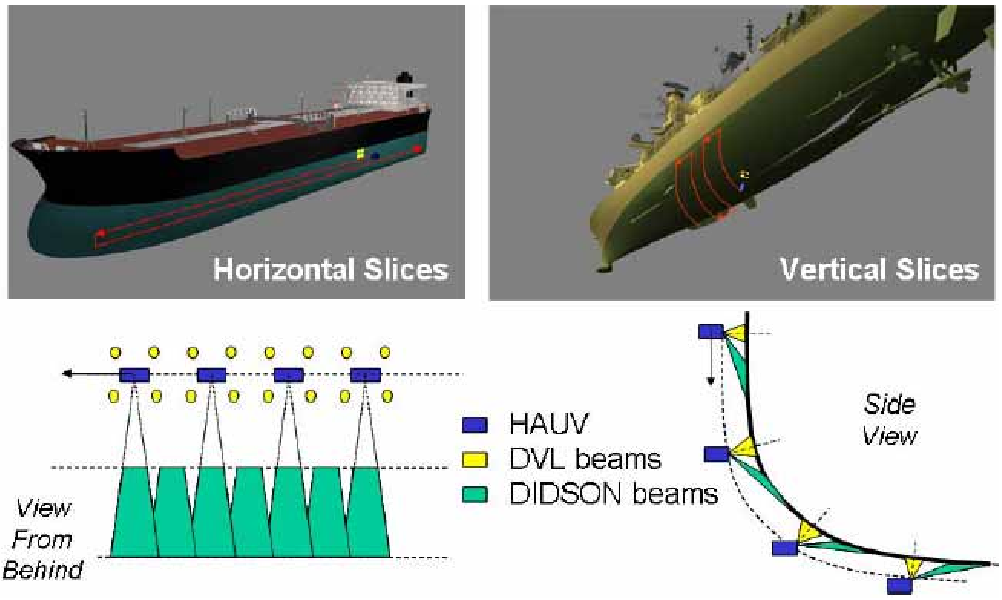

Figure 2.1. Inspection by horizontal and vertical slices. Vaganay et al. (2005).

When navigating with respect to the hull, the vehicle bearing and the DVL pitch with respect to the vehicle are controlled so as to keep the DVL pointed normal to the hull. On small curvature hulls, this condition corresponds to the four beam reporting nearly identical ranges. The four DVL ranges allow computation of the distance between the vehicle and the hull, the bearing (α) of the vehicle relative to the hull and the pitch of the DVL axis with respect to the hull (β) which equal to 0º (Figure 2.2). For reference, the six Degree of Freedom (DOF) of underwater vehicle is described in section 2.2.

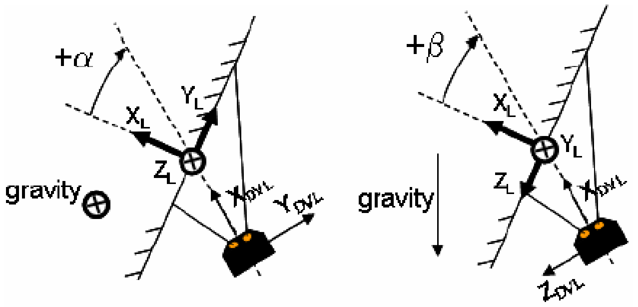

Figure 2.2. Definition of α and β. Vaganay et al. (2005)

DIDSON can be used at the front-end of an ROV and Autonomous Underwater Vehicles (AUV) as forward-looking sonar for obstacle avoidance and filling the gap not covered by left and right side-looking sonar. This device can gives near video quality images for inspection and identification of objects underwater. Figure 2.3 shows the DIDSON device and ridged casing images captured with DIDSON (Underwater structure inspection, 2006).

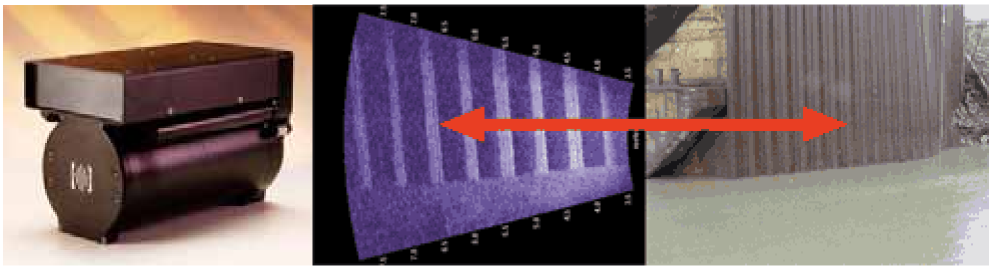

Figure 2.3. DIDSON device (left); ridged casing images taken with DIDSON (right)

Without considering the cost factors, the sonar system are very good system to use. However according to Michel et al. (2002), the two-axis *Imagenex* system used in their tests costs approximately USD $18,000, while a DIDSON system is about USD $80,000. The DIDSON image quality is significantly better than the *Imagenex*.

Meanwhile, Negahdaripour (2005) has developed a vision system for hull ship inspection based on computing the necessary information from stereo images. In stereographic technique, binocular cues are critical in resolving a number of complex visual artifacts that hamper monocular vision in shallow water conditions. The vehicle has demonstrated its ability to perform XY positioning maneuver. This stereographic technique is also based on the triangulation method. Object measurement result with this technique is almost equivalent to a monocular vision guided with laser device. If the turbidity level is getting higher, the image quality is decreasing. In this state, the laser triangulation method could provide better measurement compare with the stereographic technique. Additionally, processing time of a single camera is comparatively faster than two cameras.

In short, in order to measure a small component such as a crack surface, sonar and laser can be used for underwater application. But in term of video data requirement and high precision accuracy with inexpensive equipment, laser application is preferable. In general, a rough rule of thumb is that laser systems can operate at 2-4 times the range of optical vision (Kocak, 2005). The classical advantage of using laser beam in a computer vision system is that the image processing is easier. The visual servoing, with laser beam allows not only non-textured objects to be treated but also to optimize the closed loop control.

In order to fulfill the main objective, a few works related to the system requirement has been studied including the permeation characteristics of visible light in water, turbidity effects, laser beam detection for underwater applications and underwater laser triangulations.

2.2 Control and guidance techniques of underwater vehicles

As discussed in Fossen (1994) and Massimo (2003), the motion of marine vehicle is usually described with respect to an ROV earth-fixed inertial reference frame and a moving body-fixed reference frame (u,v,w) for ROV linear speed (surge, sway, heave) and (p,q,r) for ROV angular speed (roll, pitch and yaw rates) whose origin coincides with the center of gravity of the vehicle. Thus, position and orientation of the vehicle are described relative to the inertial reference frame, while linear and angular speeds are expressed relative to the body-fixed reference frame. Figure 2.4 shows the six Degree of Freedom (DOF) for an underwater vehicle.

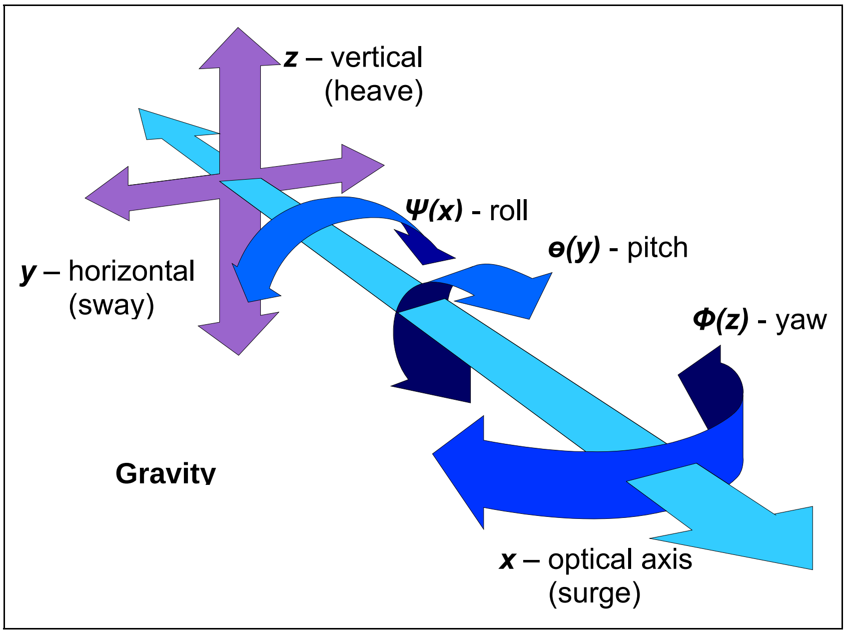

Figure 2.4 Degree of Freedom (DOF) for underwater vehicle

The vehicle kinematics nomenclatures are as follows:

$[x,y,z]^T$: ROV position relative to the earth-fixed reference frame

$[\psi,ɵ,\Phi]^T$: ROV roll, pitch and yaw angles relative to the earth-fixed reference frame

$[u,v,w]^T$: ROV linear speed (surge, sway, heave) relative to the vehicle-fixed reference frame.

$[p,q,r]^T$: ROV angular speed (roll, pitch and yaw rates) relative to the vehicle fixed reference frame.

2.2.1 Guidance techniques for underwater vehicles

The classical autopilots for underwater vehicle are designed by controlling the heading or course angle in the control loop. By including an additional loop in the control system with position feedback from the sensors, a guidance system can be designed. The guidance system generates reference trajectories to be followed by the vehicle utilizing the data gathered by the navigation system (Naeem et al., 2003). Figure 2.5 shows some important guidance laws given by Naeem et al. (2003) as well.

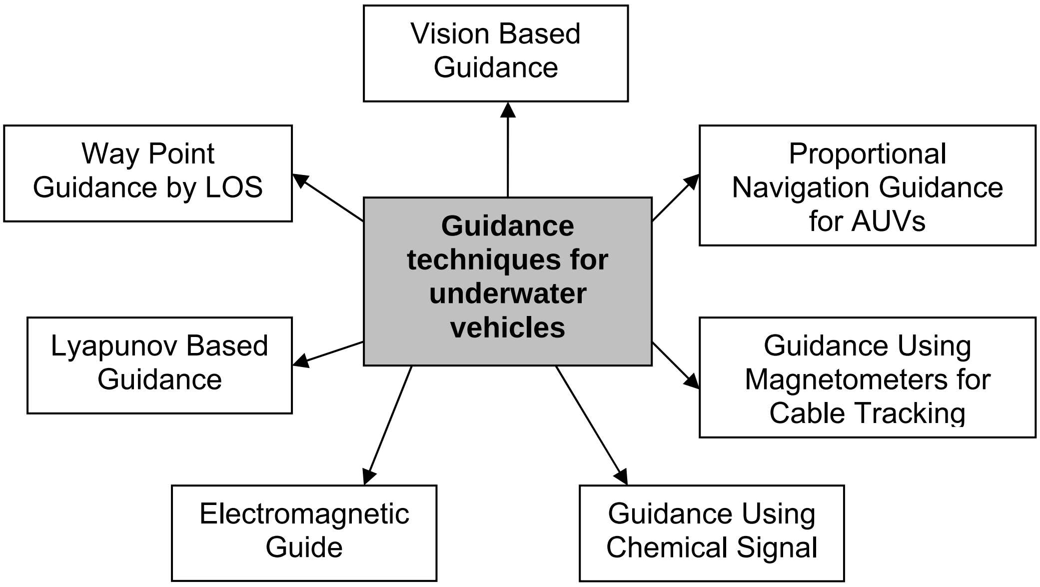

Figure 2.5. Guidance techniques for underwater vehicles

Although there a few guidance techniques are available for underwater vehicle, the main interest in this thesis is only the vision-based guidance due to the design requirement as described on section 2.1. The rest of the techniques are suitable for AUV application. In general, there are two basic approaches to vision-based control: position-based (PB) and image-based (IB). The advantages and disadvantages of these techniques has been described by Sanderson (1980) and Corke (2000). In PB systems, features are detected in an image and are used to generate a 3D model of the environment. An error is then computed in the Cartesian task space, and it is this error that is used by the control system. In IB, an error signal is measured in the image and is mapped directly to actuator commands. IB systems enjoy several advantages over PB systems. They are robust to calibration errors and do not require a full 3D reconstruction of the environment. It is also a simple matter to regulate the trajectory of image features, for instance preventing them from leaving the field of view.

However, IB has its own weaknesses. Certain control tasks can lead to singularities in the interaction matrix (or image Jacobian), resulting in system failure. IB systems also surrender direct control of the Cartesian velocities. Thus, while the task error may be quickly reduced to zero, complicated and unnecessary motions may be performed. This is particularly problem when operating in a physically limited or hazardous environment. Finally, the Jacobian is dependent on feature point depth, which may be unavailable or difficult to estimate accurately.

Combination of image-based and position-based formed another method called 2 ½ Dimension visual servoing (Malis et al., 1999). This technique sharing both benefits as mentioned previously. Another uncommon method called frameworks based which is based on linear approximations (Cipolla et al., 1997). This method required a several calibration due to low robustness on environment.

2.2.2 Vehicle control

The ROV's operator relies on the visual information in order to navigate the vehicle. However in order to minimize the task of an operator, vision based guidance are used. The basic idea underlying these schemes is that, the feature to be tracked introduces a particular geometric feature in the image captured by the CCD camera (Gaskett et al., 1999; Balasuriya et al., 1998; Briest et al., 1997; Rock et al., 1992). The vision processor then labels these features, extracts their location in the image and interprets the appearance into a guidance parameter. For example, an underwater cable introduces a line feature in the image and the edges of a cylinder introduce a rectangle. The vision processor derives the equation of the line representing the cable in the image plane given by Equation 1, which gives the direction '*q*' and position '*r*' parameters.

$$r = x\cos(q) + y\sin(q) \tag{1.1}$$

where *(x,y)* are the co-ordinates of the straight line equation. In the case of a cylindrical object, the co-ordinates of the centroid of the object (rectangle) in the image plane and the area covered by the object are derived. These parameters are then fused with other sensory parameters to determine the control references for the underwater vehicle.

Rock et al., (1992) developed a vision based system to track a dot of light generated by a laser. The hardware consists of two cameras, one of which is used to locate the target. The vision system works by scanning the image from the last known location of the target, or from the centre of the screen if the target is not previously in the view. The pixels are examined row by row, expanding outward towards the edge. If a target is found, its angle and elevation with respect to the centre of the image is evaluated and transmitted to the vision processor, while range can be found using successive images from both cameras. In general the close loop guide and control a vehicle can be illustrated as Figure 2.6.

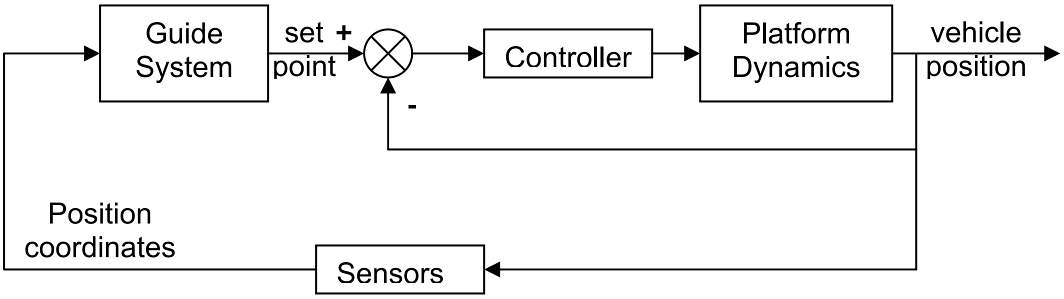

Figure 2.6. Closed loop guide and control a vehicle

The design and implementation of an advanced low cost system for the inspection of underwater structures based on a ROV has been developed by Rui et al. (2003). The system integrates a maneuver and control structures for an ROV in the context of the developments of “IES - Inspection of Underwater Structures” project. The maneuver encodes the logic required to control the vehicle to execute autonomously or assisted by the operator a complex operation. The vehicle supervisor supervises the execution of each maneuver and the plan supervisor supervises the execution of a mission plan Rui et al. (2003).

2.3 Underwater surface tracking inspection with laser device

Practically there are only three types of structured light triangulation with laser beam used, namely, single point projection, single line projection (light sectioning) and multiple line projection. The detail implementation of these techniques for underwater vehicle guidance and others related issue will be discussed in this section.

2.3.1 Light sectioning

Another related work introduced by Kondo (2004) has proposed profiling a system to determine the continuous shape of the target objects over a wide area by the light sectioning method. Sakai et al. (2004) have proposed an efficient mosaicing system of underwater images using AUV mounting the video camera with the line laser. They have shown that it is preferable to take a video from the same direction by a constant distance as much as possible to make an accurate mosaicing image efficiently.

In this technique, it is necessary to extract laser line information from the image taken by the video camera to calculate the position of AUV**.** In addition, the value of the coordinate of extended straight line on extracted laser line at both ends of image needs to be acquired. Therefore, the source image is binarized, and the straight line is extracted from this image.

2.3.2 Single point projection

Yu et al. (2001) and Kondo (2001, 2002, 2004) proposes an autonomous investigation method of underwater structures using AUVs that is implemented by initially detecting the target objects, localizing them, then approaching them by taking video images while closely tracing their shape. A laser ranging system and a tracking method based on the relative position with respect to the target objects are introduced to realize this behavior. The image-based active sensing system, consisting of a color CCD camera and laser pointing devices, is introduced to overcome sensing difficulties.

In the matter of the visibility of water around the watertight structure, the reflection points of laser beams can be detected only up to 2m distance because of the higher turbidity in the warm season. The dynamic range of the laser ranging system becomes very limited and creates difficulty in finding the target object. In this case, dead reckoning error is required to be smaller than the visible range. Once the vehicle finds the target, the method works well. Uniform lighting condition is desirable for image processing. When the vehicle cruises at relatively greater depths in which the ambient lighting is not affected by the natural sunlight, the laser ranging system works very well. But in the case of very shallow water, strong and variable natural sunlight seriously disturbs the ranging system (Kondo, 2003).

2.3.3 Other related issues

The Lamp Ray inspection system is described by Harris et al. (1999). The inspection process includes taking the user through system calibration, deployment, hull form mapping and hull condition survey. An underwater survey should not provide the owner with any less information regarding the structural integrity of the in-water portion of the hull than is available in dry dock. Through the use of innovative technology, much of it developed in the nuclear and defense industries, it is possible to image the hull structure with greater detail and at far less expense than in a traditional dry dock setting.

ROV aided dam inspection developed by Batlle et al. (2003) reported that they had a problem with the thrusters configuration. In this instant, the ROV cannot move laterally (heave movement) while keeping a constant heading. This turned out to be a problem when trying to inspect the dam while keeping a constant distance to it. Some solutions are taken into account in order to solve this drawback. This includes changing the configuration of the thrusters or adding two more thrusters to the vehicle. Another important improvement will be the addition of forward-oriented sonar. In this way, the ROV can position itself at a constant distance with respect to the wall. Thruster's configuration and pan-tilt camera are also important in this application besides the laser beam technique itself.

2.4 Underwater Laser Triangulation techniques

There a few criteria have to be taken into account in order to get the best measurement result, namely, laser device selection, hardware manipulation and feature extraction algorithm.

2.4.1 The characteristic of laser light over the undersea turbidity

The penetration of laser light and its characteristic over the undersea turbidity has been developed by Hoshino et al. (2004). They found that, the effect of wavelength of the light on the attenuation characteristic is huge and only the blue light (650nm wavelength) can penetrates the water up to the depth of 55m. The extinction coefficient increases in proportion to the increase of the turbidity. It becomes possible that, the laser device is also suitable for the undersea measurement system. Furthermore, the permeability condition does not change by the output of the laser and that the power of the penetrating laser in turbid water attenuates exponentially.

2.4.2 Hardware manipulation

In terms of hardware manipulation, range-gated imaging system is one of the advance techniques used to enhance image quality and visibility in turbid conditions. It is normally preferred not just due to its high range and high resolutions performance, but also because of its robustness in terms of motion insensitivity. The range-gated is well known for its capability to avoid backscattering effect from turbid medium. It basically consists of a pulsed laser system, a control and synchronous logics and a high-speed gated camera. The camera gate time is synchronously matched with the laser system, in order to discriminate backscattering noise from the actual reflected target irradiance (Tan et al., 2005)

2.4.3 Feature extraction techniques for centroid searching

By selecting the best laser device that can penetrate deeply with range-gated imaging system, the measurements are not complete without a proper feature extraction technique. There are several methods available to define the centroid of the laser beam. One of those method is by the detection of circles in the image using the Hough Transform technique. But this technique also has its limitation since the Gaussian has very weak derivatives, meaning it is difficult to extract the centroid of the laser beam (Hsin-Hung Chen et al., 2004).

The mean location (centroid) within the search window of the discrete probability image is found using moments (Horn, (1986); Freeman et al., 1996; Bradski, 1998). Problems with centroid computation for face tracking have been identified (John et al., 2003; Bradski, 1998; McKenna et al., 1999; Comaniciu et al., 2003). The direct projection of the model histogram onto the new frame is known to introduce a large bias in the estimated location of the target and the measurement is known to be scale variant.

Although the proposed system is mainly depending on the laser, there are some disadvantages of using laser device has to be taken into consideration. For instance, light is absorbed by water (which may also be useful) and by the debris produced during processing. Furthermore, light may be scattered by the water surface, suspensions and bubbles, and possible power loss due to water cooling (Kruusing, 2002).

In brief, this section had discussed the factors that contribute to the accuracy in laser range measurement technique. As a preliminary study, the theoretical explanation in this section will be tested.

2.5 Summary

In this chapter, the ship hull inspection technology, underwater laser and underwater guidance and control have been reviewed. Since underwater laser application has undergone several positive developments recently, small issue regarding its weakness as mentioned in previous section can be neglected. However the main challenge is to perform high speed loop control respond and precision in measurement as well. Selection of proper hardware devices and programming technique may overcome this problem. In order to develop the system, the need of the particular goals have been taken into consideration. Among the key design issues addressed are Cartesian platform as an ROV, pan-tilt camera, laser device positions, feature extraction techniques, real time programming language, calibration methods, controller, ship hull prototype and underwater environment. These subjects will be discussed in details throughout the thesis.

CHAPTER THREE
THEORY

3.0 Introduction

A theoretical explanation of the research is discussed in details in this chapter. A Cartesian platform is used to emulate the ROV’s movement. It is similar to setup which had been done by Lots et al. (2001) to emulate the six DOF of the ROV. Assuming the underwater environment characteristics are known, this research will focuses on how to develop the vision-based tracking system itself. The permeation characteristics of visible light in water, turbidity effects, laser beam detection for underwater applications and underwater laser triangulations, are also discussed in this chapter.

Scaled-down ship hull section is developed and used as the target object, painted with the actual anticorrosion paint (dark maroon). Grids of 10cm x 10cm are marked on the ship hull model surface so that it can provide some mean for the visual observation, measurement and analysis. Finally, this research adopts a set of metrics and performance criteria from feedback control theory to characterize the dynamic performance of the tracking system.