APPLICATIONS OF MOTION CAPTURE TECHNOLOGY IN A TOWING TANK

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The present paper gives an overview of the history and technology of motion capture and the various cameras' arrangements that can be used in a towing tank. A precision analysis is presented which maps the system accuracy over the measurement volume, investigating the influence of markers orientation and motions on the precision of the system. The motion capture system is further configured to broadcast position information as NMEA packets for real time feedback control, thus simulating a very precise indoor positioning system for autonomous vehicles. The paper then details a selection of case studies based on experiments undertaken at the Boldrewood towing tank that present new capabilities made possible by the availability of the motion capture systems. This includes applications in sports engineering, free running models, sea keeping and autonomous vehicle control. Finally, possibilities of future work are discussed.

1 Introduction

The limited availability of large ocean basins for research and education has led the University of Southampton to purchase two Qualisys motion capture systems for its new Boldrewood towing tank: one for above water measurements and one for under water measurements. The two systems can also be coupled for hybrid measurements.

This technology is versatile and has allowed the University to develop new experimental methods used for various Education, Research and Commercial projects. Using reflective markers, the measurements can cover single point's trajectories in space or six degrees of freedom for rigid bodies. By arranging multiple motion capture cameras, it is possible to create a volume of space where the dynamics of objects can be measured to known levels of precision and broadcast in real-time. The flexibility offered by the setup and the arrangement of motion capture cameras enables model dynamics to be measured in air, in water and across the water surface.

2 History of model tracking in naval architecture

Model tracking is an essential element of manoeuvring tests. In the early days of free running experiments, this type of test was performed on lakes. The main system to track models consisted in several theodolites stations on the side of the lake as pictured on Figure 1.

Figure 1 – Model tracking at Horsea Lake (photo courtesy of QinetiQ)

Each station was manned by a member of staff who was tasked to follow the model through the theodolite aiming at an easily discernible object on the model (typically a coloured point on a mast or a light bulb). Each station would record the bearing to the model and by triangulating the data from all shore stations, it was possible to recreate the path of the model during the experiment [1]. The precision of this system was limited and did require a significant amount of post-processing.

With the development of photography, a new technique was later developed [2] and mostly used in covered ocean basins. Light bulbs were mounted at the bow and stern of a self-propelled model. The path of these bulbs (and hence the model) was recorded photographically by multiple exposures on a single plate or film.

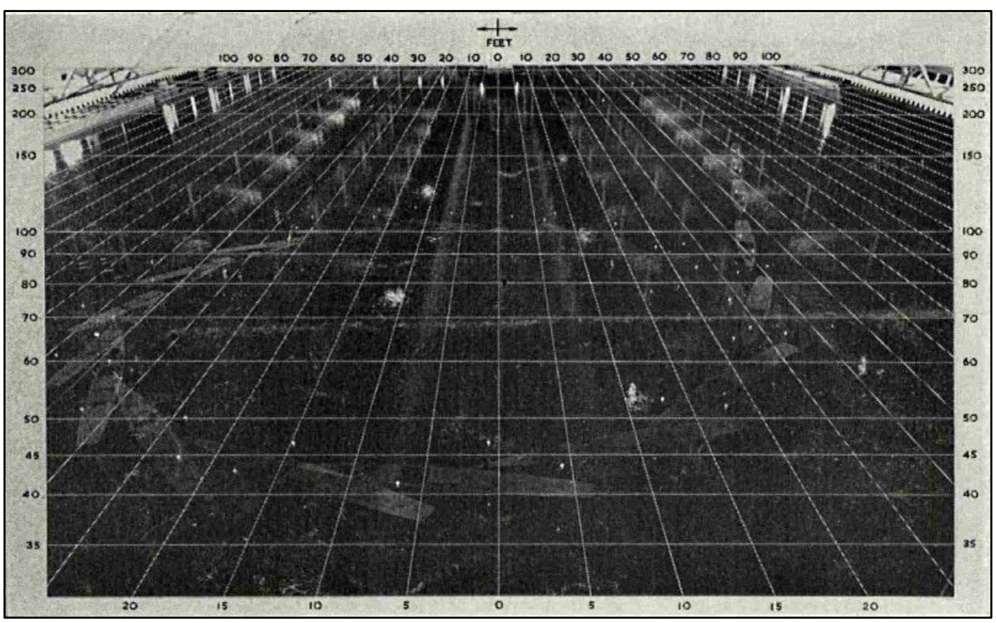

Figure 2 – Photography tracking at the Haslar Ocean Basin [1]

As shown in Figure 2, the resulting photograph shows the position of the bow and stern lights at various points during the experiment, but the path is distorted by the perspective effect. This was corrected for by using a specially constructed perspective grid which was placed over the photograph to allow for the position of the lights to be converted in their correct cartesian coordinates. This method was a lot more precise and reliable but still required a fair amount of post-processing after the experiments were conducted. This method was extensively used until the late 1990s.

In parallel, and when budgets do not allow the use of expensive facilities as large indoor ocean basins, or precise waves not required, manoeuvring experiments are sometimes conducted on lakes or sheltered sea areas. In that case, the most common tool for tracking a free running model is the Global Positioning System (GPS) [3]. Although precision is limited to several meters, modern GPS systems are consistent enough so they can be used to provide a good estimation of the turning circle diameter for example.

After 2000, motion capture technology progressively became the method of choice for tracking free running models in large manoeuvring basins, as shown in Figure 3.

Figure 3 –Free running model fitted with motion capture markers during manoeuvring test in an ocean basins (photo courtesy of WUMTIA)

3 Motion Capture Technology

3.1 Overview of the technology

Motion capture technology has always been closely linked to the cinema industry. The foundations for today's technology go back to 1915 and a technique called rotoscoping [4] that was used in various animation movies. In 1959, an analogue bodysuit fitted with potentiometers allowed for the first real-time motion capture. In the 1980s, several companies started to work with reflective markers and cameras. When the available computing capacity exploded in the late 1990s, the post-processing became more automated to reach today's standards where real time is now the norm. Motion capture technology is nowadays widely used in the cinema and video games industry, but also in the scientific world, with a wide range of applications.

A modern motion capture system uses infrared lights and several cameras to work. Each camera emits infrared light which is reflected by reflective markers [5]. Each marker's reflection is acquired as a 2D image by each camera (see Figure 4).

The first step is the system calibration. The wand calibration method uses a calibration kit that consists of two parts: a L-shaped reference frame (see Figure 5) and a calibration wand. The calibration wand consists of a T-shaped wand with two reflective markers at each end of the T bar. For the University system, it is designed so the distance between the two markers is either 300 mm and 600 mm, the exact distance being measured by the manufacturer by laser and given for each wand for a higher precision in the calibration.

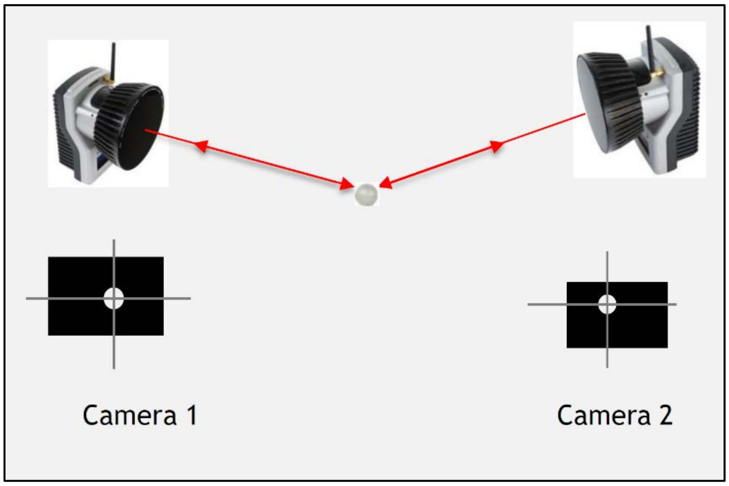

Figure 4 – Principle of motion capture technology

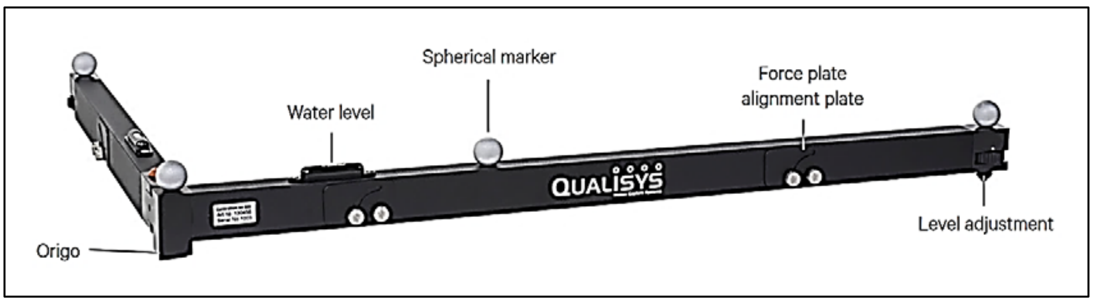

Figure 5 – View of the calibration L frame (www.qualisys.com)

The L-shaped reference frame needs to be placed so that the desired coordinate system of the motion capture is obtained. It is best if all cameras in the system can see all markers on the reference structure. This is not an unconditional requirement but it gives the highest accuracy. The calibration wand is then moved inside the target measurement volume in all three directions. This is to assure that all axes are properly scaled. The calibration algorithms will extract each camera's position and orientation by evaluating the camera's view of the wand during the calibration.

Once calibrated, the system is able to measure real time position markers fitted on a model by triangulating each camera 2D image and orientation. A non-deformable model can also be fitted with several markers and acquired as a rigid body. In that case, the software is able to calculate real time six degrees of freedom motions for the model.

The University motion capture systems can also be combined with third-party sensors such as force plates or inertial measurement units.

3.2 Possible arrangements in a towing tank

Using a motion capture system in a towing tank presents some challenges, as the water restricts the access to most of the volume where the model operates. As the underwater system has been used less frequently in the tank this section will focus on the above water configurations as the same principles apply to both.

The above water system consists of four wide-angle cameras (70°) and four narrow angle cameras (49°). This offers an infinity of combinations, but experience shows that three different arrangements cover most of the work undertaken in the Boldrewood towing tank.

Arrangement A

For free running experiments with large or fast models, it is necessary to cover the largest possible tank length so sufficient data can be captured. By placing the wide-angle cameras on the side of the tank at a height of about 2.50 m (using heating pipes as support) and the narrow angle cameras on the tank rails as shown on Figure 6, it is possible to cover a tank length between 8 and 10 metres. This is just about enough to characterise the behaviour of a fast model in following seas [6].

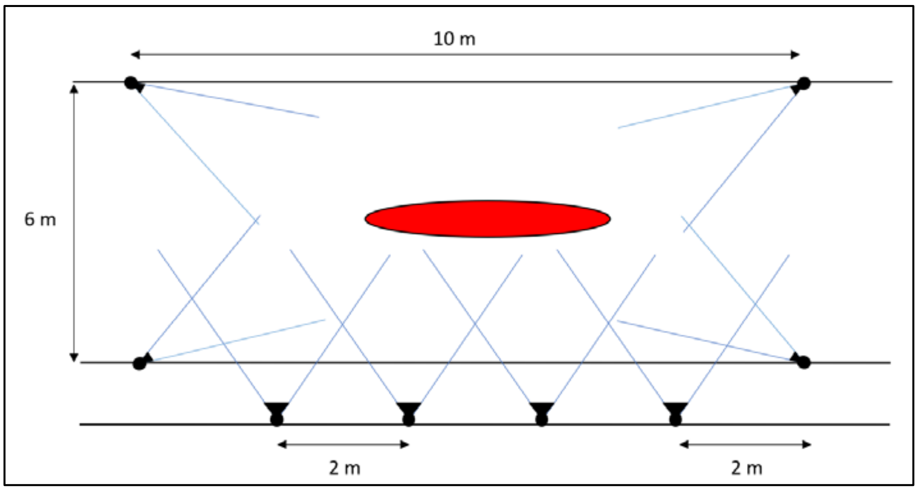

Figure 6 – Cameras' arrangement A

Arrangement B

The second arrangement is used for smaller and slower free running models or static tests when the model is moored in the tank. These tests only require a small volume to be covered. In this case, it was found that using four wide angle cameras works well. Two of them are placed on the side of the tank and two of them on the carriage (see Figure 7).

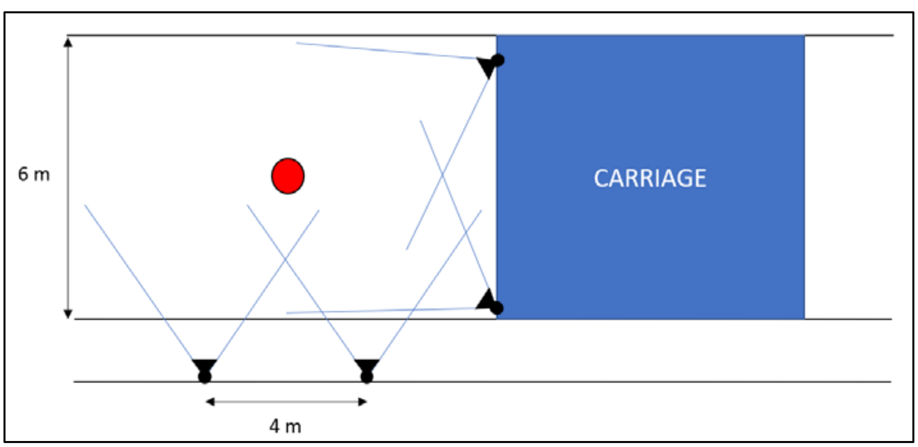

Figure 7 – Camera's arrangement B

Arrangement C

Camera's arrangement C is used when the model is connected to the carriage dynamometer. As the model is static relative to the carriage, the covered volume is very small. Using four wide angle cameras as described on Figure 8 gives good results, but care has to be taken with regards to the obstructions present in the moonpool (various beams, platform, dynamometer post, etc). The main challenge is the calibration, as there is a limited number of locations for the reference L frame.

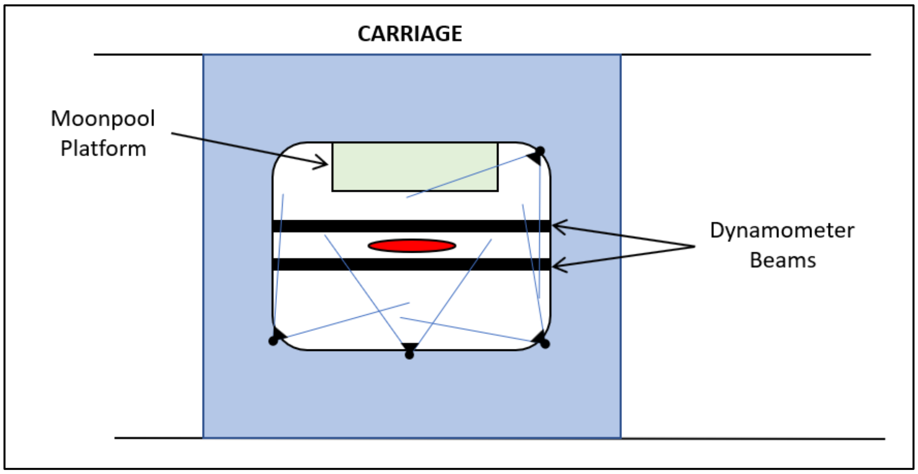

Figure 8 - Cameras' arrangement C

3.3 Precision analysis

A precision analysis was carried out for the arrangement A described in section 3.2. The chosen methodology for this analysis consisted in using two calibration wands provided by the manufacturer (see section 3.1) and to compare the measured distance between the two wand markers (301.1 mm or 601.3 mm) whilst moving the wand around the measurement volume.

The system was calibrated using the 601.3 mm wand. The calibration quality as provided by the motion capture software is given in Table 1.

Table 1 – Calibration quality

Camera -	**Points -**	**Avg. residuals [mm]**	
1	1198	1.026	
2	728	0.586	
3	750	1.134	
4	739	0.999	
5	580	0.809	
6	904	1.210	
7	866	0.942	
8	984	1.290	
Std. deviation of wand length		0.674	[mm]

It is recommended by the manufacturer to achieve a maximum standard deviation on the wand length of 1 mm, which was the case here.

It was decided to investigate the precision of the system for three types of motions (see Figure 9):

a) Vertical: the wand is held vertically and moved around the calibrated area;
b) Horizontal: the wand is held horizontally and moved around the calibrated area;
c) Rotation: the wand is moved around the calibrated area whilst being rotated.

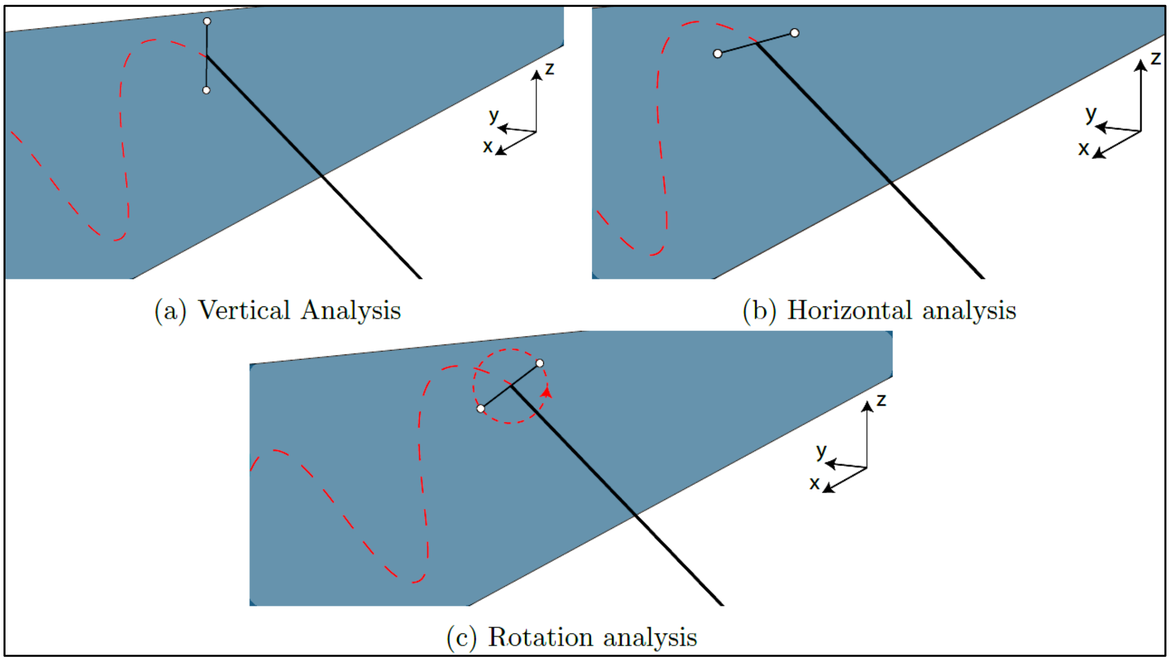

Figure 9 – Precision investigation methodology

The calibration actually consists in a random combination of these three types of motions.

It should be noted that the wand was moved by hand at the end of a 4 m carbon fibre pole, so the motions were not perfect.

Table 2 – Precision investigation results

		Min.	Max.	Average		Standard Deviation	
Wand	**Type of motion**	**[mm]**	**[mm]**	**[mm]**	**[%.LWAND]**	**[mm]**	**[%.LWAND]**
301.1	Vertical	-2.42	2.76	-0.84	-0.28%	0.26	0.09%
	Horizontal	-1.95	1.93	-0.11	-0.04%	0.44	0.15%
	Rotation	-9.56	3.71	-0.54	-0.18%	0.91	0.30%
601.3	Vertical	-2.98	-1.17	-2.02	-0.34%	0.19	0.03%
	Horizontal	-3.68	0.49	-0.94	-0.16%	0.69	0.11%
	Rotation	-21.92	14.34	-1.39	-0.23%	1.42	0.24%

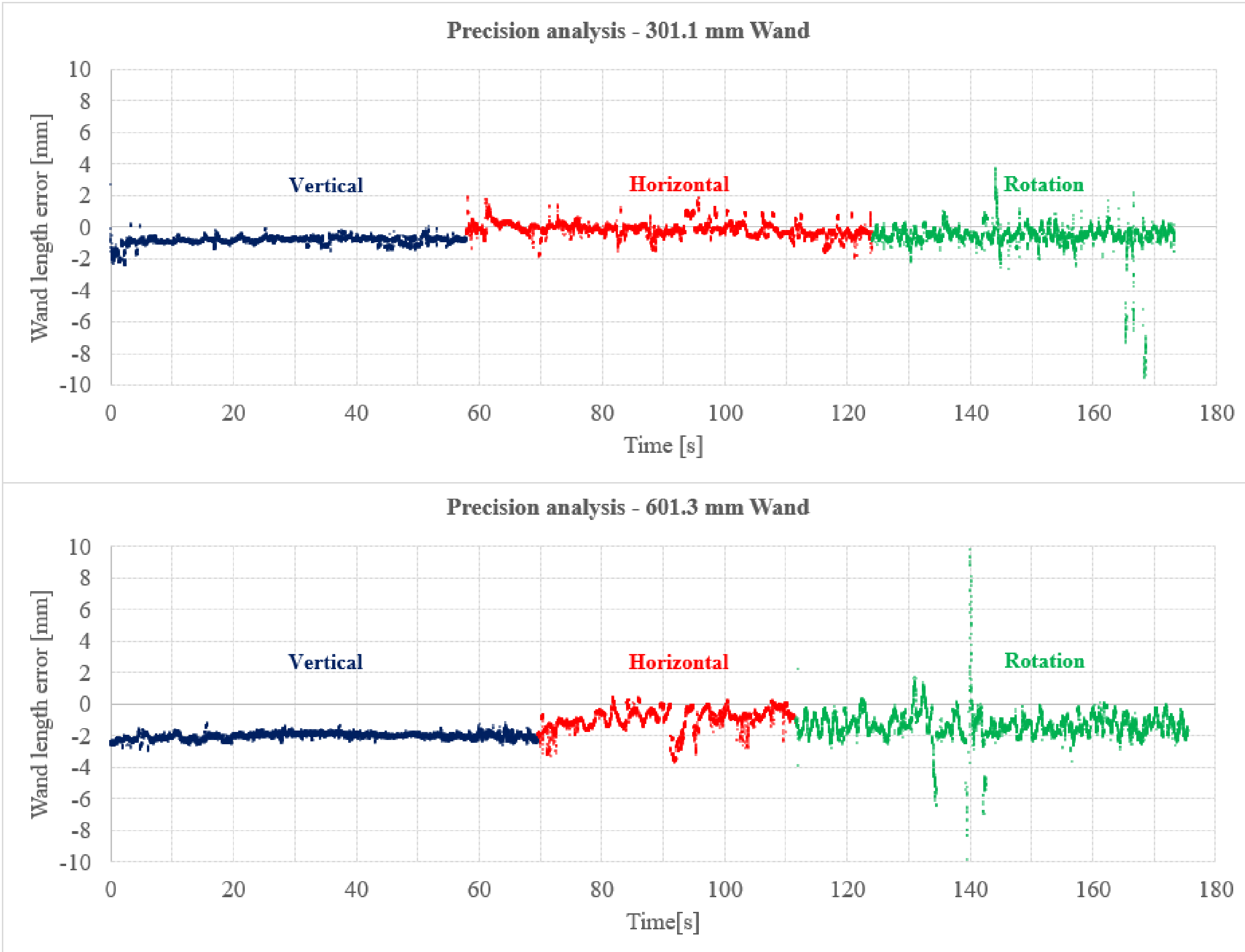

Figure 10 – Precision investigation for both wands

The results shown in Figure 10 and in Table 2 show that the average error is the smallest for horizontal analysis, but the vertical one is more consistent. It is believed that the reason for the lack of consistency for the horizontal analysis is the orientation of the wand relative to the cameras on the rails: the markers were mostly in the same horizontal plane as these four cameras, which makes it more difficult to distinguish them as separate markers at all times.

The rotation analysis is overall similar to the horizontal one but shows a few large spikes during the measurements. This did not come out a surprise as the manufacturer had advised that this type of motions is the most difficult for the system to deal with.

It is interesting to note that the distance between the markers was always underestimated during this experiment. It is not known why this is the case. It is also reassuring to see that the orders of magnitude of the wand length standard deviations for the calibration and the precision experiment are the same.

Overall, the results of this analysis are very satisfactory. This particular camera arrangement covers the largest possible volume in the Boldrewood towing tank with the number of cameras currently owned by the University and therefore is the arrangement that offers the greatest flexibility.

The same precision study has not yet been performed with the other arrangements presented in section 3.2, but the calibration standard deviations given by the motion capture software are lower in these cases, which strongly suggests that the precision is higher with arrangements B and C. The main reason for this is that the covered and calibrated volumes are much smaller.

3.4 Indoor positioning system

This section describes the setup of the Qualisys Track Manager (QTM) as a real-time indoor positioning system. As described in 3.1, the motion capture system calculates real time six degrees of freedom data from multiple rigid bodies that can be accessed by using the Software Development Kit (SDK) provided by the manufacturer [7]. A host computer is connected to the QTM server via Ethernet, and then translates the QTM data into a NMEA compatible format, which is forwarded to the model computer via WiFi.

The data forwarding process was implemented in Python 3 using the QTM library and a regular socket connection to an existing server in the model computer. The data stream is down-sampled from 100 Hz to 10 Hz, which is fast enough given the dynamics of the models tested so far.

The data is then processed on the model computer with the appropriate algorithm depending on the experiment. An example of this indoor positioning system being used to control an Autonomous Surface Vehicle (ASV) is described in section 4.2.

4 Case studies

4.1 Sports engineering

Motion capture systems have been used to quantify human kinematics in sport and health sciences for many years but the recent application of these techniques in a towing tank has enabled new Sports Engineering research into aquatic sports.

The first project consisted in measuring the behaviour of a free running kayak as part of an MSc project. Both the hull and the paddle handle were acquired as rigid bodies and therefore their respective motions measured (see Figure 11 – A/B). This allowed the relationship between the paddle motions and the kayak speed and acceleration to be characterised for various stroke rates and wave conditions [8].

Another MSc project assessed the hydrodynamic performance of a rowing oar. For this, a rowing boat was attached to the side of the tank (see Figure 11 – C/D). Both the above water system (8 cameras) and underwater system (6 cameras) were installed and coupled to track the motions of the oar shaft in air and the blade in and out of the water. Interferences (mostly air bubbles) were observed near the water interphase, but the results allowed the motions and deflections of the oar to be assessed. These measurements, along with force measurements at the junction of the paddle and the boat and at the attachment of the boat by the tank side were used in a detailed analysis of the rowing performance of the blade [9].

Lastly, both motion capture systems have recently been used within a swimming pool to capture the kinematics of a freestyle swimmer’s body and arms both above and below the water. This allowed arm velocities and orientations to be determined over a typical stroke cycle. This work is ongoing and includes an extensive assessment of the errors over the combined measurements domains (air and water) and will be covered in more detail in future publications.

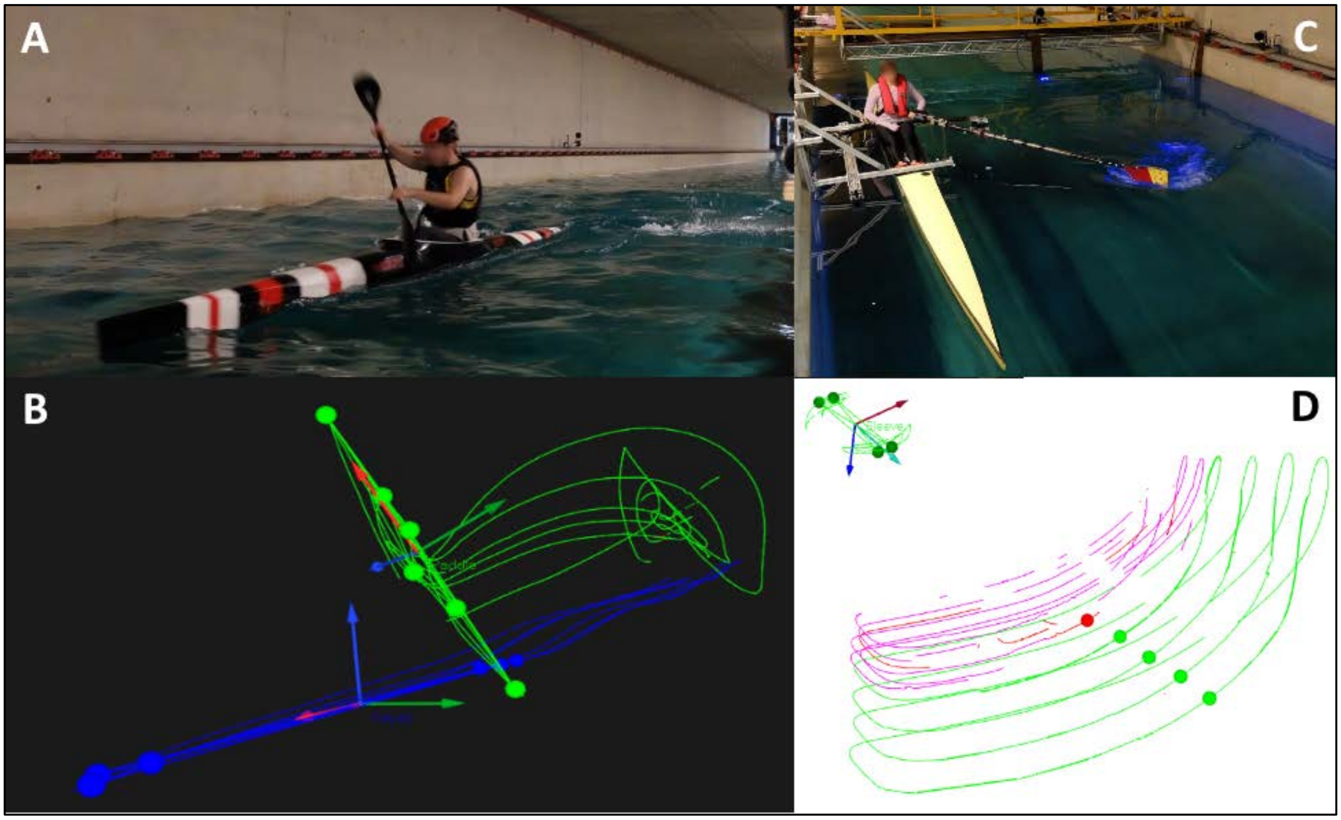

Figure 11 – Sports engineering applications

4.2 ASV with indoor positioning system

The ASV “SMARTY” is a three degrees of freedom surface vehicle designed for demonstration purposes at the University of Southampton. It is fitted with four brushless DC motors acting as thrusters. The motors are rotated 45° in the XY plane in order to provide vectorised thrust (see Figure 12).

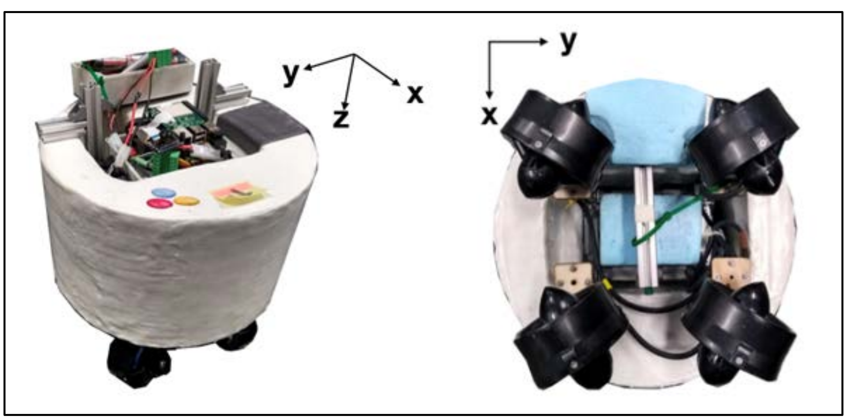

Figure 12 – Views of the ASV SMARTY

The ASV is equipped with an onboard Linux powered computer (Raspberry Pi 3B+), WiFi and Bluetooth connections, gyroscope and accelerometer sensors and a camera. A SenseHat board is added for visual feedback purposes. Two battery packs can power the system up to 2.5 hours. The vehicle can be operated either by a remote controller, or in autonomous mode using the information obtained from the motion capture system, via a host computer, as described in section 3.4. For this application, only the X-Y position and platform heading are employed for both tracking and control purposes. This feedback is sufficient to control a 3 degrees-of-freedom platform such as SMARTY.

For the remote mode, the desired thrust input is obtained from a remote controller (RC) that connects to the vehicle computer via Bluetooth. The RC provides a normalized thrust reference described in a coordinated system fixed to the rigid body (platform), which is internally converted to pulse width modulation references for the motor drivers. When operating in autonomous, the platform uses the real-time feedback from the QTM as a positioning system to follow a predefined collection of waypoints. Two empirically tuned proportional derivative controllers were included to control concurrently the heading and position of the ASV.

The system connection described in Figure 13 was tested for both remote and autonomous modes. The remote mode consisted in an operator controlling the ASV and trying to describe a C-shaped trajectory with a 400 mm side. The Qualisys system provided real time position feedback to the user, who used this input to control the platform movement. For the autonomous mode, the same C-shaped trajectory was sent as reference to the position controller.

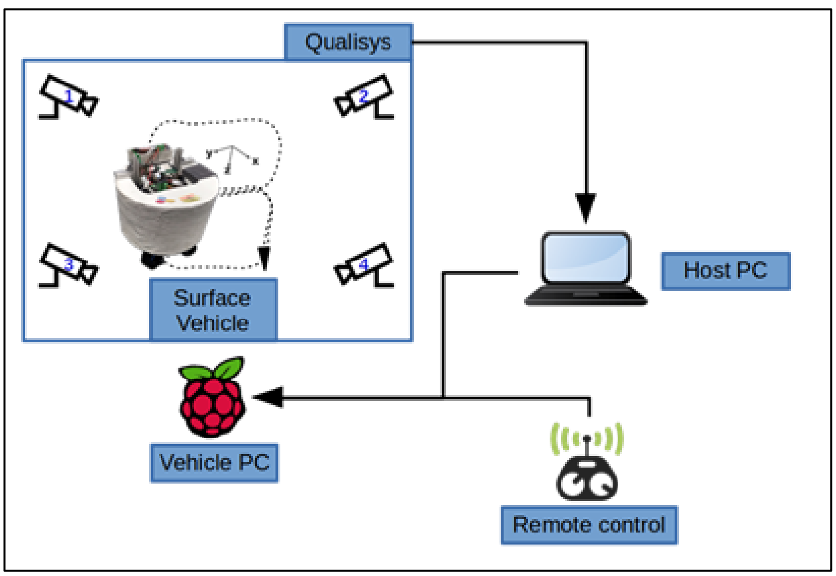

Figure 13 - System connection diagram. The Qualisys tracking system provides live position and heading to the ASV via the host computer

The resulting position trajectories are shown in Figure 14 and Figure 15, for the remote and autonomous modes respectively. It must be noted that these tests were performed for illustrative purposes.

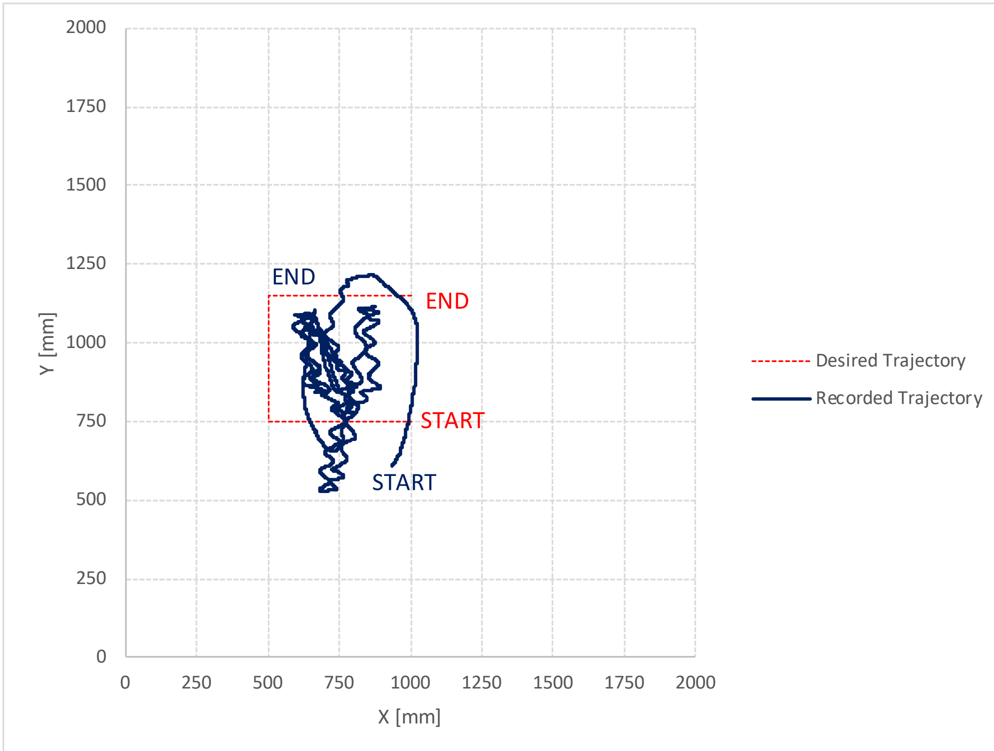

Figure 14 - Trajectory described by ASV SMARTY while being operated in remote mode

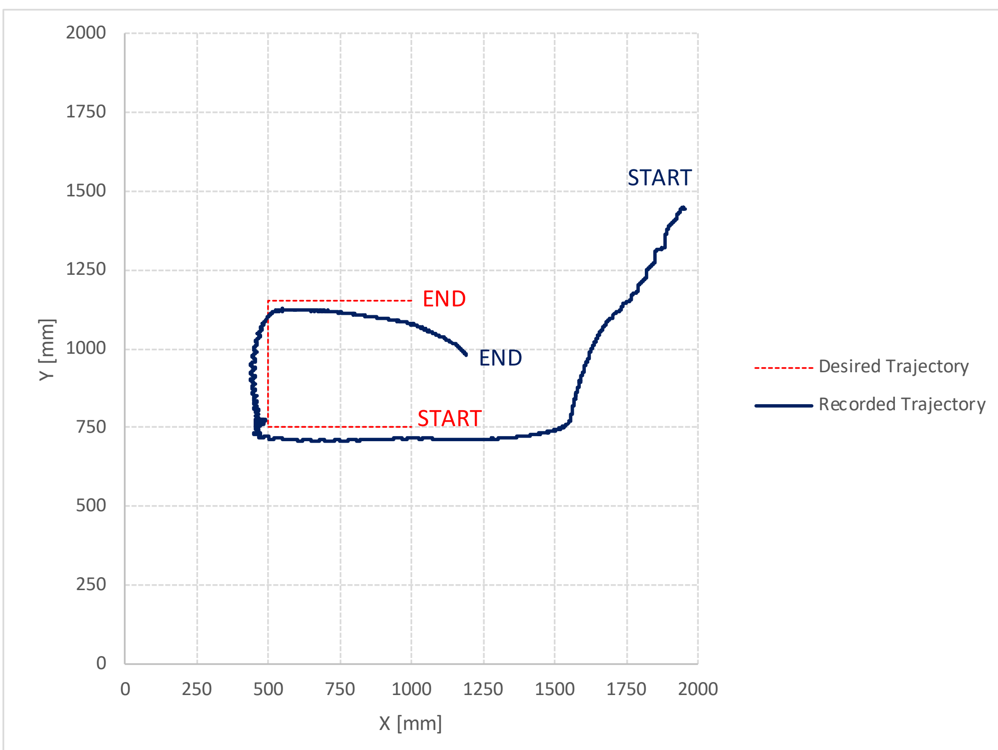

Figure 15 - Trajectory described by ASV SMARTY while operating in autonomous mode using the Qualisys system for real time position feedback

For the remote mode operation, a low-quality trajectory was obtained as a consequence of the intervention of a human operator that used the position information from Qualisys as feedback. A clear C-shaped trajectory cannot be distinguished, and the platform displacements where within a range 550 mm along the X-axis and 750 mm in the Y-axis. This operation mode was employed to illustrate the difficulty of following a path only relying on the position information, rather than using a more natural visual feedback (i.e. the operator observing the platform directly).

In the autonomous mode, the observed behaviour is more consistent with the C-shaped trajectory, when compared against the remote mode. However, it must be noted that there is a confounding effect coming from the position controller and the position feedback system (Qualisys), which is reflected as part of the platform position error. Another important effect that was perceived during both type of tests, was the presence of a permanent low-frequency oscillation in the position vector. It was later identified as the natural oscillation of the platform due to the difference between the centre of gravity and the effective thrust plane coming from the motors. This configuration produces a systematic error reflected as the above-mentioned oscillations.

5 Future work

There are many possibilities for future work offered by the motion capture systems in the Boldrewood towing tank.

An experiment with a free running sailing yacht [6] performed in the Boldrewood towing tank showed that it is possible to use small foam floaters fitted with reflective markers as wave probes (see Figure 16).

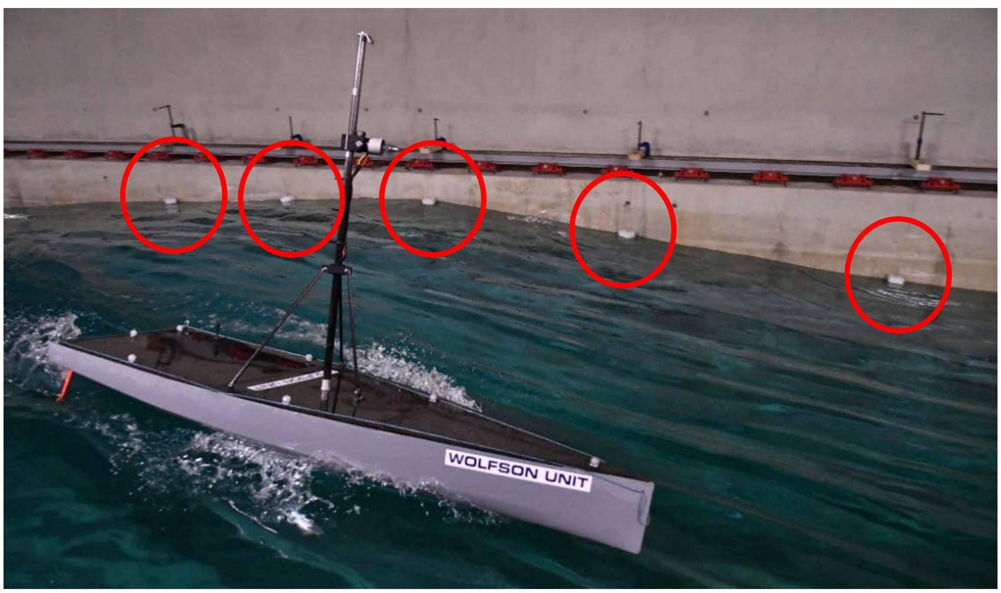

Figure 16 – Use of floats with reflective markers as wave probes [6]

As the wavemaker fitted in the towing tank is capable of generating oblique waves in the tank, it should be possible to use multiple small floaters as wave probes to generate a three dimensions map of the free surface of the tank when this type of waves is being generated.

To date, the carriage is not equipped with its drive system, so it can only be used for static experiments. Once the carriage can move along the rails, it will be possible to install motion capture cameras on its front face and therefore to track a free running model for the whole length of the tank. With a small enough model (due to the limited available width of 6 m in the tank), it will then be possible to perform self-propelled manoeuvring experiments such as zig-zag tests. In theory, it will also be possible to feedback the forward component of the model speed to the carriage drive system so that the distance between the model and the forward face of the carriage remains reasonably constant. The main anticipated challenges for this type of experiments are the possible influence of the carriage vibrations on the quality of the data and also the limitations of the cameras' arrangement. From experience, having all the cameras in the same plane can cause problems to the motion capture system calibration. This could be overcome by designing and manufacturing special brackets.

The follow-up of the work described in 4.2 is to carry out dynamic positioning tests in various configurations of wind and waves. A twin shaft model fitted with both stern and bow thrusters is currently being built and will be used to develop a dynamic positioning algorithm.

As proven in section 3.3, the precision of the motion capture system is very high. It is planned to perform a similar precision study about the six degrees of freedom given by the motion capture system, comparing them to on-board inertial measurement units. Ideally, this will be performed when the carriage drive system has been installed so the self-propelled model can be tracked for the entire length of the tank and sufficient amounts of data collected.

6 Conclusion

Motion capture systems are now widely used in industry and research. They provide an easy to install and use and versatile solution to a large range of problems. These systems have been extensively used by students, researchers and engineers at the Boldrewood towing tank.

The precision study presented in this paper shows that the motion capture technology provides very accurate results when it comes to tracking models, both above and under water.

There is still some work to be done to fully explore the capacities, issues and benefits of the motions capture systems, and we are very much looking forward to all the projects that will require their use.

7 Acknowledgments

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8 References

[1] R. N. Newton, “Turning and manoeuvring trials,” in *Symposium of ship trials and service performance analysis*, Newcastle/Tyne, 1960.

[2] R. N. Newton, “New facilities at admiralty experiments works, Haslar,” *RINA Quarterly Transactions Vol. 104 No. 4*, October 1962.

[3] B. Deakin & D. Buckland, “Recent advances in radio controlled model testing,” in *The second Cheasapeake power boat symposium*, Annapolis, Maryland, 2010.

[4] J. Conditt, “Engadget,” 2018. [Online]. Available: https://www.engadget.com/2018/05/25/motion-capture-history-video-vicon-siren/.

[5] “Qualisys Track Manager User Manual 2019.3”.

[6] E. Gauvain, “The un-restrained sailing yacht model tests - A new approach and technology appropriate to modern sailing yacht seakeeping,” in *The 23rd Cheasapeake sailing yacht symposium*, Annapolis, Maryland, 2019.

[7] “QTM Real-time Server Protocol Documentation,” 2019. [Online]. Available: https://docs.qualisys.com/qtm-rt-protocol/.

[8] F. Suva, “Measuring coupled kayak and paddler motions within a towing tank,” MSc Research Project Thesis, University of Southampton, 2017.

[9] D. Dalmau, “Development of a test methodology for assessing the hydrodynamic performance of rowing paddles,” MSc Research Project Thesis, University of Southampton, 2017.