DESIGN OF MOTORISED MODULAR FLOATING BRIDGE

Ting Qi Ern Kaylene[1], Jeremy Sim Tze Shiong[2]
[1]Cedar Girls' Secondary School, 1 Cedar Avenue, Singapore 349692
[2]Defence Science and Technology Agency, 1 Depot Road, Singapore 109679

Abstract

Floating bridges have multiple applications such as military uses to transport troops and tanks as well as for civilian purposes to temporarily or permanently bridge across bodies of water during times of emergency. Modular floating bridges consist of manoeuvrable components that are positioned to link up to form longer bridges in cases where a singular bridge is too resource demanding or time-consuming to construct. Motorised floating bridges however, make use of remote autonomous technology to position itself without the aid of human support. While the development of autonomous positioning technology has been explored, the necessary methods of aligning multiple moving pontoons precisely for successful linkage has faced several roadblocks. There are several existing technologies available such as the Inertial Navigation System that has been used in the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines and ships, that may be useful in this capacity as well. This paper will look into the design of an unmanned modular floating bridge of up to 2km for deployment and use in the shortest possible time.

Introduction

Floating bridges are unique structures which make use of their buoyant nature to float on the surface of the water as compared to traditional bridges which are anchored to the seabed. While floating bridges are more sensitive to changing environmental conditions such as water levels, wind speeds and currents, they are particularly useful in areas where the seabed is too shallow, deep or unstable and the construction of traditional bridges is not feasible or practical.

Modular floating structures have the unique advantage of being scalable and customisable to various needs. The modular design means that the different components of the bridge can be attached and linked to form different lengths and widths depending on the intended use. The portability of modular floating bridges via azimuth thrusters allow for quick and easy deployment and transport from the storage facility to the connection site. Manually operated floating bridges such as the M1940 Treadway Bridge and M1938 Infantry Footbridge have been used in various combat scenarios, requiring soldiers to quickly assemble and deploy the floating modules. While this method is effective, motorised floating bridges bring the benefit of reducing manpower and assembly time.

Figure 1: CNIM PFM Motorized Floating Bridge (militaryleak.com)

Motorized designs typically support heavier loads, including armored vehicles and equipment as demonstrated in Figure 1, which are essential in military logistics. For example, Class 60 floating bridges can support MLC 70 traffic, offering enhanced operational capability compared to lighter manually operated bridges. Motorized floating bridges often incorporate advanced stabilization technologies that allow for better performance in adverse weather conditions and strong currents. Many motorized floating bridges can be adjusted or repositioned as needed, allowing them to accommodate changing tactical situations or water levels. This adaptability is less feasible with manually operated bridges, which are typically fixed once constructed.

Figure 2: Deployment of modular floating bridge (asme.org)

Figure 3: Trucks crossing modular floating bridge (asme.org)

The modular floating bridge discussed in this report consists of various components: pontoons/barges (terms are used interchangeably in this report), thrusters, anchors and locking mechanism.

Unmanned technologies such as autonomous aerial refuelling have been developed and applied since 2020 by an Airbus MRTT test aircraft. Such technologies make use of the Global Positioning System (GPS), or vision-based navigation systems to track the position of the receiver and tank aircraft (Ren & Quan, 2024)[1]. Naval based autonomous systems are more limited in development with Unmanned Surface Vehicles usually being brought aboard a host ship for refuelling (R. Galway, 2008)[2]. Hence the primary concern regarding motorised floating bridges is the means of controlling the modules with precision and safety in the face of various environmental factors.

Positioning and Connection

Navigation systems:

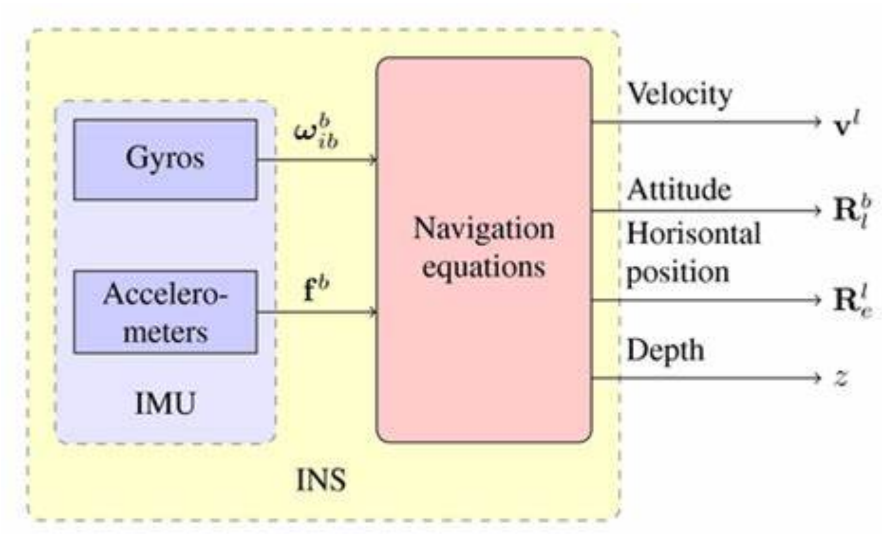

Figure 4: Inertial Navigation Systems processing (blog.naver.com)

Several positioning systems are used together to achieve the stable state required to align the moving floating barges before the ramps and connection pins can be inserted. One such sensor is the Inertial Navigation System (INS). The INS uses a gyroscope and accelerometer to obtain orientation and acceleration data of the barges respectively. Velocity and position measurements are subsequently integrated from the acceleration via an external processor. However, there is an accumulation of inertial drift from small acceleration data errors that gradually cause the system to produce largely inaccurate data due to integration. Even the most accurate INS with a standard error of 10 micro-g accumulates a drift of 50 metres in 17 minutes.

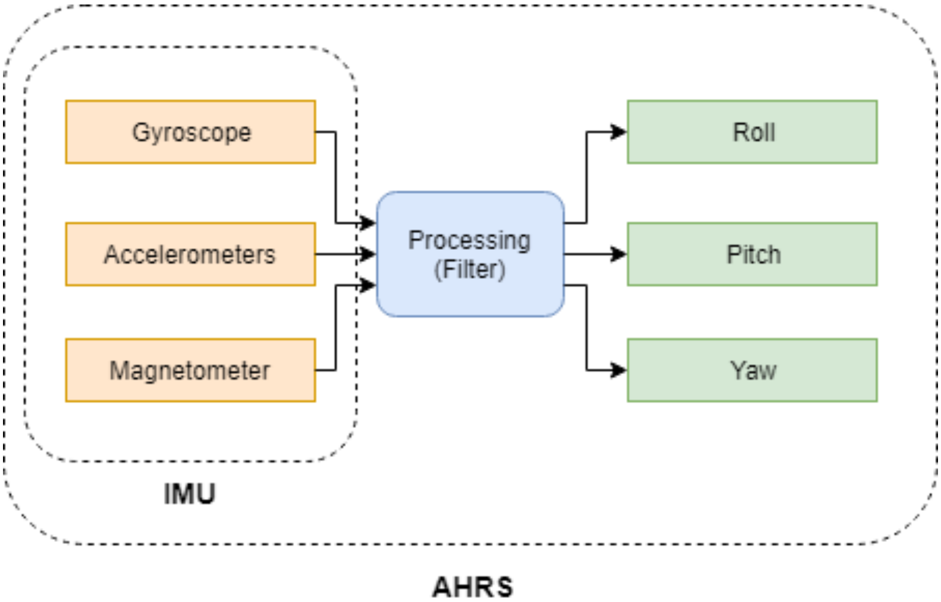

Figure 5: Attitude Heading Reference System (uavnavigation.com)

Another system used is the Attitude and Heading Reference System (AHRS). Using a gyroscope, accelerometer and magnetometer, the AHRS accurately measures the orientation of the object, (in the case of a floating barge, the roll, pitch and yaw). This system uses on-board processing to provide stable orientation data in real time. The above diagram demonstrates the basic computing process of the AHRS. Several filters can be used, such as the Kalman filter that combines predicted values with observed measurements to produce a weighted average estimate that is more accurate than the singular value.

The Global Positioning System (GPS) has been employed to periodically correct the position drift of the INS for calibration purposes. GPS satellite data provides absolute drift-free position data via waves and receivers, allowing it to complement the INS and increase its accuracy (Hoshizaki et al., under submission).

Together, the three systems can be used as an Integrated Sensor Fusion System, helping to increase accuracy (Tomaszewski et al., 2017)[3] and precision of the real time data and updates. If one system should fail (eg. GPS system jamming/spoofing[4] due to high electronic warfare), the other 2 systems can continue to provide essential data to function and guide the barges. The fusion system would be more costly but also more reliable for use in times of crisis.

Motion control:

Figure 6: Azimuth thrusters (marinelink.com)

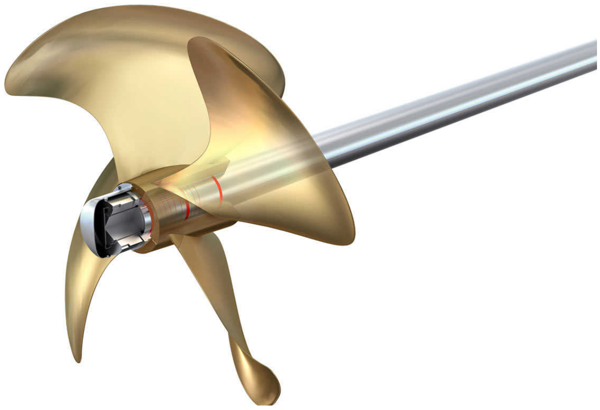

Figure 7: Fixed pitch propellor (kongsberg.com)

This motorised modular floating bridge uses azimuth thrusters to steer and direct the pontoons for transport and alignment. Azimuth thrusters can rotate 360 degrees about the vertical axis, providing more flexible steering than fixed pitch thrusters as seen in Figures 6 and 7. This allows moving force to be generated in any direction as compared to fixed thrusters that can only direct the pontoon in one direction and requires a rudder for steering. The thrusters are important for transport to the deployment site and the subsequent remote linkage of each module while accommodating the changing environmental loads – wind, water levels and current speeds.

The thrusters which are situated at the bottom of the pontoon are vulnerable to grounding damage when the pontoons approach land for anchoring. The reason that they cannot be situated higher is that this causes them to be less effective (V. Desai-Patil et al., 2015)[5]. As such, there is a need for the thrusters to be retractable either vertically or horizontally.

The thrusters are to be controlled remotely while processing remote feedback from the navigation systems, allowing it to adjust accordingly to the loads and environmental conditions (M. Bibuli et al., 2020)[6].

Anchoring

Spud anchors have the ability to anchor barges and other marine vessels into the sea bed, regardless of how shallow the waters are. This is useful for stabilising and securing the pontoons of the modular floating bridge. Hydraulically actuated spud poles are lowered into the sea and penetrate the substrate, effectively locking the modules in place. The anchoring force of the spud is dependent on the friction generated between the outer surface of the spud and the soil sediment (Sarkar et al., 2015)[7].

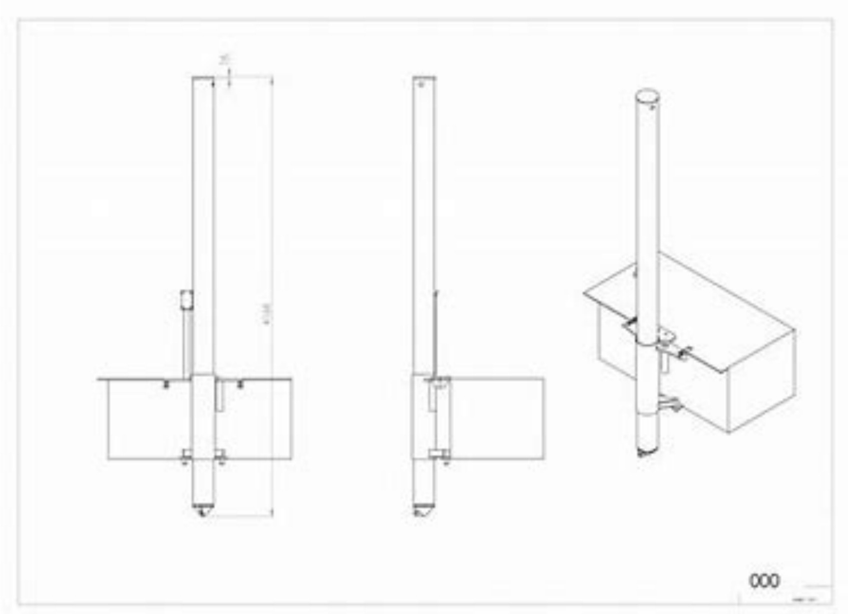

Figure 8: Spud pole anchor (europontoons.com)

In the design of this floating bridge, spud anchors are used to secure some of the barges to the ground, with the large barges having 4 spuds each, 2 on each side.

The barges are interconnected via long steel ramps that are equipped with rollers and guiding pins for locking and extending purposes. During deployment and linkage, floating barges use data from sensors and the azimuth thrusters to align themselves to one another, enabling the guiding rails of one barge to slide longitudinally into the sliding connection pin of another barge, securely locking the system in place. This process is repeated along subsequent barges until the entire floating bridge of desired length is reached.

One of the most significant challenges at this stage is the positioning of the barges against one another when both crafts are in motion due to wave and wind conditions. On top of that, after the connection has been made, the azimuth thrusters must continue to stabilise the bridge to prevent it from drifting and pulling against the spud anchor.

Pontoon Oscillation

The effect of the moving weight of the tanks on the floating bridge results in deflection and stress, as seen in the below diagram, reducing the smoothness of travel across the bridge and its load capacity. Over time, this may lead to wear and tear of the connectors. Hence it is essential to optimise the rigidity and elasticity of the pontoons and connectors such that disruptive motion is minimised.

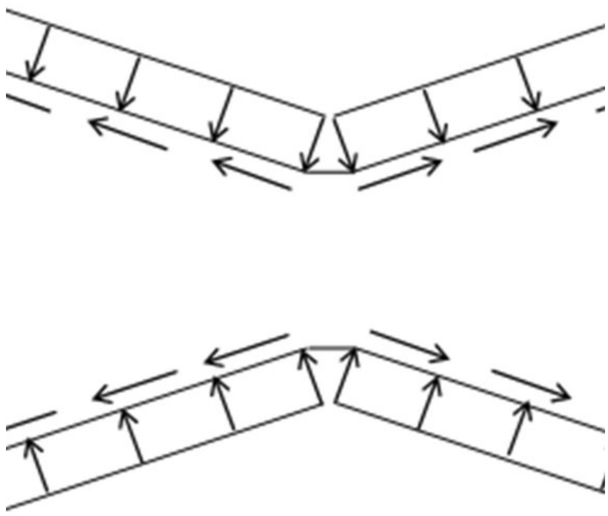

Figure 9: Pontoon displacement when carrying loads (researchgate.net)

The length of the floating bridge should be longer than the wavelength at any point in time, ensuring that the forces from the waves do not act over the whole length of the structure simultaneously. The vertical forces acting on multiple different segments of the structure would average out, minimising the overall displacement. If the wavelength was greater than the structure length, the bridge would have a ship-like behaviour, with larger oscillations (A. Halim Saleh, 2010)[8].

A hydraulic damper can be used to reduce the impact of the wave load on the structure. Placed horizontally between adjacent barges, the dampers reduce lateral motion and excessive yaw. Vertical dampers between the surface deck and the pontoon can reduce both heave and avoid exacerbating unwanted pitch if placed symmetrically. Numerical simulations or software models should be used to trial the bridge's dynamics under load and wave conditions. From this, the damper positions and angles can be fine-tuned to ensure that energy dissipation doesn't amplify unwanted motions. This is with the intention that less stress on the bridge will also result in smoother operation and reduced chance of breakage. Material selection for pontoon construction is also important when analysing the elasticity and ability to absorb hydrodynamic forces.

Conclusion and Future Work

Motorised modular floating bridges have a lot of potential to be used in a quick fashion in times of civil emergency and during war. Although research has been done on positioning systems and azimuth thrusters, it is usually not in regards to modular pontoons for remote controlling. The main challenge with constructing a temporary floating bridge spanning 2 km is the heave motion and dynamic stability of the structure supporting crossing vehicles of at least 70 tons simultaneously. Simulations and rigorous testing such as wave simulations and weight tolerance tests need to be conducted to ensure that the connection of barges can take place smoothly without human support in the midst of varying sea state levels and that the structure can maintain stability and robustness (J. E. Fowler et al., 2006)[9]. Future advancements may see the incorporation of Artificial Intelligence to remotely process and compute data from the sensors to translate into motion control of the barges, ensuring a smoother deployment process without the need for human supervision.

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