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DEVELOPMENT OF A MARINE TRAFFIC SIMULATOR ON GOOGLE MAPS

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ABSTRACT

The Google Maps application is an excellent tool for many navigational purposes. Recognizing the potentials, this study shows the development of a Marine Traffic Simulator (MTS) by utilizing the capabilities of the Google Maps API in conjunction with the ship manoeuvring model, namely Nomoto's K-T Model. The aim is to facilitate the real-time analysis of a ship's manoeuvring motion directly on Google Maps, making it universally applicable to waterbodies worldwide. The research attempts to develop a sophisticated web-based application that simulates a ship's planar motion and dynamically controls the virtual ship in real time. While Nomoto's K-T Model is fundamental for assessing a ship's manoeuvring motion, it merely provides a rudimentary estimation. The ultimate goal of this research is to act as a springboard to lay the groundwork for integrating more precise and intricate models of ship motion directly into the robust framework of the Google Maps platform. This research aspires to advance the capabilities of marine traffic simulation by seamlessly blending the Google Maps API's technological prowess with sophisticated ship motion models.

Keywords: *Marine Traffic Simulator, Google Maps, Nomoto's K-T Model, Planar Motion, Dynamic Control*

1. INTRODUCTION

Marine traffic comprises vessels' complex and dynamic movement across the world's waterways. Thus, the increasing complexity of the global maritime traffic calls for advanced tools for monitoring and managing vessel movements.

A marine traffic simulator (MTS) plays a significant role in this context by replicating and analyzing the movement and interaction of vessels in a virtual environment. These simulators are valuable for training and research purposes, developing strategies, and the planning and management of marine traffic for emergency response and avoiding collisions. Kazuhiko Hasegawa et al. 2001 developed an intelligent marine traffic simulator for congested waterways [1]. Such a simulator can be used with automatic collision avoidance function of target ships [2]. Qualitative and quantitative analysis of congested marine traffic environments is also an application of such simulator [3]. It can also be useful while designing waterways [4]. Hiroko Itoh et al. 2001 developed [5] a real-time marine traffic simulation for multi-PC system based on data from actual observations and sailing ship information. This is used to observe high-speed navigation through Tokyo Bay, a highly congested sea area. Shimpei Watanabe et al. 2008 described a detailed method [6] of an inland waterway traffic simulator. Fumihiki et al. 2010 researched [7] about marine traffic simulation of the straits of Malacca and Singapore. M. Numano et al. 2015 evaluated the safety of vessel transit in congested sea areas such as busy ports and coastal waters [8].

Google Maps, a widely used and highly detailed mapping service, incorporates various cutting-edge features including satellite imagery, and offers a peerless level of geographic information and user accessibility. These make it an ideal tool for integrating marine traffic simulation capabilities. Leveraging the robust capabilities of Google Maps, a marine traffic simulator can provide a tangible and accessible platform for visualizing and analyzing traffic patterns. This integration allows for real-time tracking of vessels, simulation of various traffic scenarios, and navigational hazards in an interactive virtual environment.

The "Nomoto Model", a well-recognized mathematical representation of ship manoeuvring motion, was first introduced by Kensaku Nomoto et al. 1957 [9]. Kensaku Nomoto et al. 1957 approached the problem of evaluating ship steering quality. Earlier, it was rigorous to determine the coefficients relating to the equations of motion for a particular ship. This is where Kensaku Nomoto et al. 1957 devised an approach to solve those coefficients with the help of the "Transfer Function". Even though this process involves some experimentation, it eliminated the need for rigorous and expensive experimental set-up needed earlier. Kensaku Nomoto, in 1960, presented a result of a series of experiments in his paper with cargo, tanker, and whale-catcher under various conditions i.e. ballasted, full-loaded, and half-loaded to make it easier to determine the value for two coefficients K and T steering indices [10]. The model has been revised again and again from 1957 onward with different ship types, under different sea conditions, and various conditions. For instance, Kensaku Nomoto et al. 1960 re-examined the model proposed by him in "Analysis of Kempf's standard maneuver test and proposed steering quality indices" for supertanker [11]. The effect of roll motion on ship manoeuvrability by the "Nomoto Model" was evaluated by Yoshimura et al. 2011 [12].

By incorporating the Nomoto Model directly into the robust framework of the Google Maps platform, the developed simulator will pave the way for realistic simulations that facilitate better decision-making and strategic planning in maritime operations.

2. MATHEMATICAL FORMULATION

2.1 Governing Equation

"Nomoto Model" has a more straightforward form. The required coefficients here, in this model, directly relate to the manoeuvring characteristics of a vessel and thus can be used to evaluate the manoeuvrability of a ship. It is a 2nd order differential equation that can be expressed as follows,

$$T\ddot{\psi} + \dot{\psi} = K\delta$$

Or, $$T\dot{r} + r = K\delta$$

Where,

ψ = Heading angle (°)

$r = \dot{\psi}$ = Rate of turn (°/s)

δ = Rudder command (°)

L = Ship length (meters)

U = Initial forward speed (knots)

K, T = Nomoto Steering or Manoeuvring Indices

K', T' = Non-dimensional Indices

2.2 Experimental Data on *K* and *T*

The manoeuvring indices K and T are made dimensionless with the ship length L and initial forward speed U by:

$$K' = \frac{KL}{U} \quad \text{and} \quad T' = \frac{TU}{L}$$

Figure 1 and Figure 2 shows a graphical representation of K' and T' (Non-dimensional indices) in relation to the displacement of ships of various types, as they have been published by Kensaku Nomoto on the First Symposium on Ship Maneuverability in Washington in 1960 [10, 13].

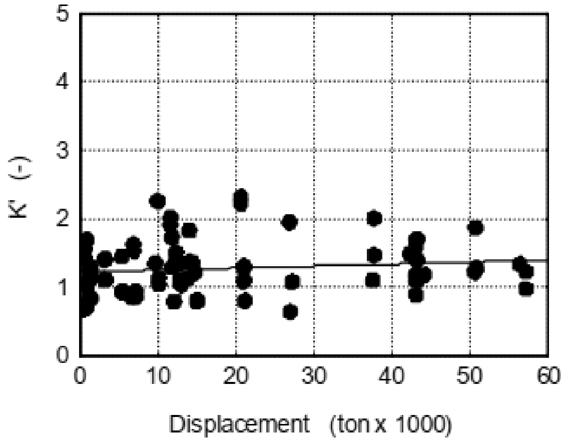

Figure 1. Non-Dimensional Presentation of K Index of Nomoto

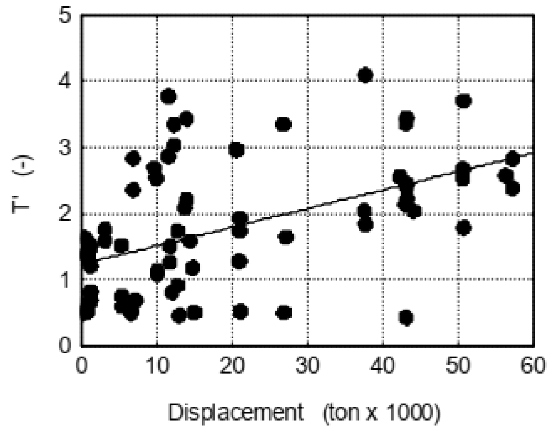

Figure 2. Non-Dimensional Presentation of T Index of Nomoto

Figure 1 & Figure 2 show that K' does not depend very much on the ship size, but that T' increases with the ship size.

2.3 Runge-Kutta 4th Order Method

The Runge-Kutta method was devised by two German mathematicians, Runge in 1984 and extended by Kutta a few years later [14]. The fourth-order Runge-Kutta method (RK4) is widely used for solving ordinary differential equations (ODEs). The general formula for the approximation is,

$$y_{n+1}(x) = y_n(x) + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4),$$

Where, n = 0, 1, 2,3, ……

$k_1 = hf(x, y)$

$k_2 = hf\left(x + \frac{h}{2}, y + \frac{k_1}{2}\right)$

$k_3 = hf\left(x + \frac{h}{2}, y + \frac{k_2}{2}\right)$

$k_4 = hf(x + h, y + k_3)$

3. METHODOLOGY

3.1 Aim of the Research

The objective of this study is to develop three main codes, namely – 1. Trajectory Code, 2. Google Maps Code & 3. Control Code in JavaScript. These three codes in conjunction will build the foundation of the Marine Traffic Simulator (MTS).

3.2 Trajectory Code

The trajectory code utilizes Nomoto's K-T equation and uses Runge-Kutta's 4th order method to solve the equation,

$$\dot{\psi} = \frac{d\psi}{dt} = r = f(t, \psi, r)$$

$$\ddot{\psi} = \frac{dr}{dt} = \frac{K\delta}{T} - \frac{r}{T} = g(t, \psi, r)$$

These two functions are used in Runge-Kutta's 4th order method by using a "while loop" in JavaScript to continuously produce the trajectory of a given ship. This code takes the following inputs:

1. Non-dimensional Indices (K' and T')
2. Ship Length (L) in meters
3. Ship Speed (U) in knots
4. Initial Heading (Ψ) in degrees
5. Rudder Command (δ) in degrees

And produces the following outputs:

1. Instantaneous Heading (Ψ) in degrees
2. Instantaneous Rate of Turn (r) in degrees/second
3. x and y position of the ship from origin.

All of these, combined, produce an animated trajectory of a ship moving forward. The code also produces two graphs as follows-

1. Heading vs. Time (Ψ vs. t)
2. Rate of Turn vs. Time (r vs. t)

3.3 Google Maps Code

The Google Maps Code draws the trajectory calculated by the Trajectory Code directly on Google Maps. This requires the aid of the Google Maps API. From its Geometry Library, various functions are applied in the code. Thus, four primary functions in JavaScript are created:

1. **Function A:** This function calculates the distance between two geographic coordinates (latitude and longitude). It uses the "computeDistanceBetween" function of the Geometry Library.
2. **Function B:** This takes the distance from Function A and calculates a new distance using the Trajectory Code.
3. **Function C:** This calculates new geographic coordinates from the distance calculated by Function B. It uses the "computeOffset" function of the Geometry Library.
4. **Function D:** Finally, this function draws a line joining the new geographic coordinates to simulate a ship moving forward on Google Maps.

All of these functions combined in JavaScript produce an animated trajectory of a given ship directly on Google Maps.

3.4 Control Code

The Control Code allows for the control, i.e. steering of the ship while moving across a waterbody on Google Maps using a control device such as a keyboard, joystick, or steering wheel. This code takes the physical input of the control device and converts it into virtual data for use in the Trajectory Code. While the ship is moving forward, the code allows for the instantaneous change of the Rudder Command which in turn allows for the instantaneous change in the ship's Heading and Rate of Turn.

These three codes combined in JavaScript allow for the simulation of a given ship on Google Maps.

4. OVERVIEW

The GUI (Graphical User Interface) of the simulator is as follows in Figure 2.

Figure 3. GUI of the Marine Traffic Simulator

The upper left section of the MTS represents the input parameters.

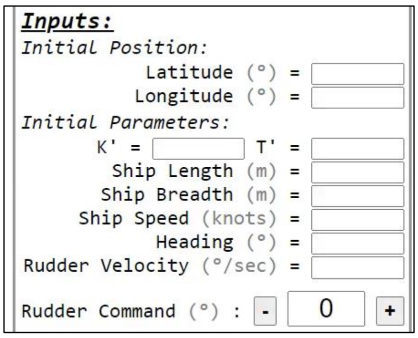

Figure 4. Input Parameters

Here in Figure 4, the Latitude & Longitude values are taken by manual typing or by a single mouse click on the desired location on the map. The Rudder Command is changeable at any point during the ship's motion and the ship will react accordingly.

The bottom left section of the MTS represents the current/instantaneous values-

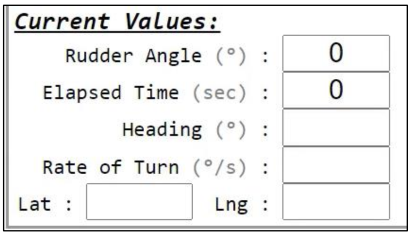

Figure 5. Current/Instantaneous values

Here in Figure 5, the Rudder Angle value changes to the Rudder Command value according to the Rudder Velocity. The Latitude & Longitude values are the instantaneous geographical position of the ship.

The middle section of the MTS represents Google Maps where the simulation of the ship is shown-

Figure 6. Simulation of a ship moving on a waterbody on Google Maps

The right section of the MTS represents the two graphs (Heading vs. Time and Rate of Turn vs. Time) in Figure 7 & Figure 8. These graphs are Live Graphs i.e. they continuously update as the ship moves forward.

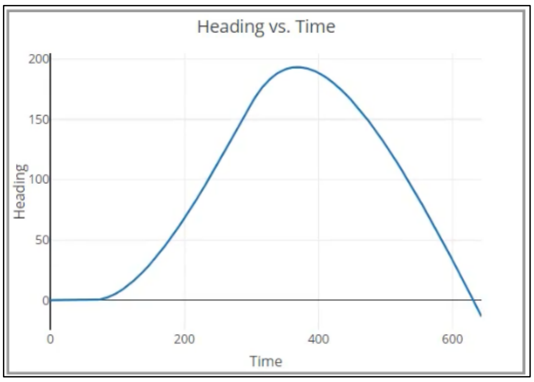

Figure 7. Live Graph of Heading vs. Time

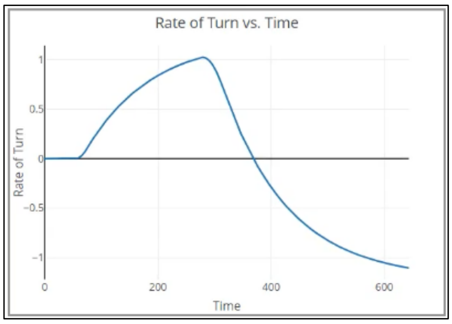

Figure 8. Live Graph of Rate of Turn vs. Time

5. VERIFICATION

For verification, the real trajectory of an actual VLCC Tanker [15] in Figure 9 is compared with the simulated trajectory of a ship having the same input parameters. The parameters of the VLCC Tanker as given [15], are: Length = 320 m, Breadth = 58 m, Volume of Displacement = 312,600 m^3, Speed = 15.5 knots, Rudder Speed = 1.76 deg/sec.

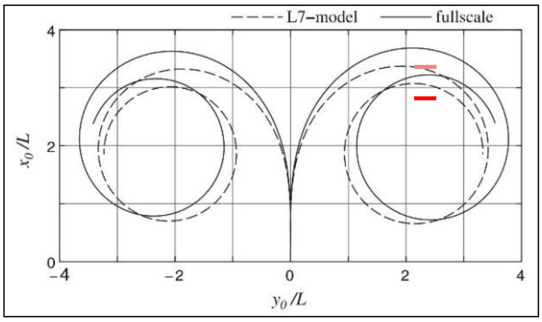

Figure 9. Trajectory of the VLCC Tanker

The trajectory is extracted point-by-point from Figure 8 to Google maps with utmost accuracy. Then, for the K' and T' values, Figure 1 is used.

From Figure 1 & Figure 2, it can be seen that K' remains approximately constant for high displacements, whereas T' increases with displacement. Since the trajectory of a high displacement ship is being simulated, the values of K' and T' are taken 1.4 & 2.9 respectively. The comparison is as following-

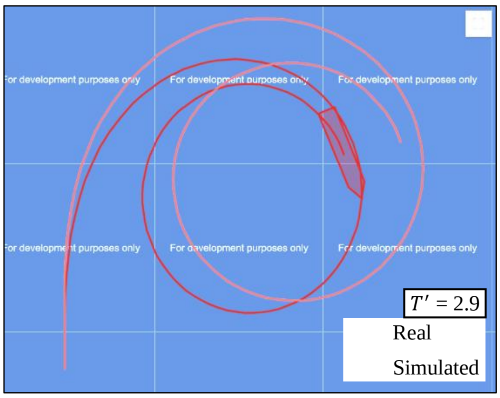

Figure 10. Real and Simulated trajectories

As it can be seen from Figure 10, there is quite a bit of difference in the trajectories. This can be attributed to the fact that a T' value of 2.9 only corresponds to a displacement of 60,000 tons [13]. Since the simulated ship has a much higher displacement, a higher T' value can be used to see whether the accuracy increases or not.

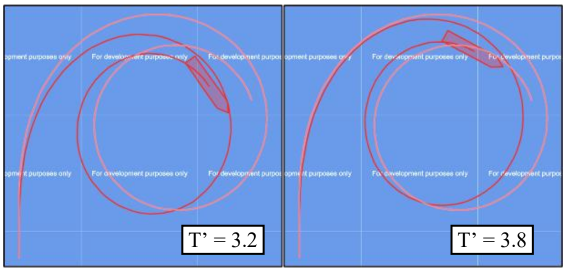

Figure 11. Increase in accuracy with increase in $\boldsymbol{T'}$

From Figure 11, it can be seen that an increase in T' increases the accuracy of the simulated trajectory.

6. LIMITATIONS

There are some limitations of the simulator due to the simplicity of the "Nomoto Model". They may be described as follows-

i) The current simulator only works on the North-East quadrant of the Earth's surface.

ii) In this study, only certain parameters are randomized as inputs.

iii) The simulator ignores the effect of wind, waves, currents, and other phenomena experienced in marine environments.

7. CONCLUSION

From the introductory section, upon discussing the evolution of the "Nomoto Model", it has been shown that even though the model has been used multiple times for simulating marine traffic, incorporating it into the framework of Google Maps as a research topic is yet to be explored. This research has bridged the gap and contributed to understanding the unexplored topic.

Some of the recommendations for further research can be as follows-

i) There is further scope for randomizing other input parameters.

ii) A more capable simulator can be developed to plot multiple trajectories of multiple ships at a time.

iii) More sophisticated manoeuvring models can be employed for more precise and accurate simulation such as ‘'Manoeuvring Mathematical Group (MMG) Model" [15], "Abkowitz Model" etc.

iv) The code can be designed to operate on each quadrant of the Earth's surface.

The ultimate goal of this research is to act as a foundation to lay the groundwork for integrating more precise and accurate models of ship motion directly into the framework of the Google Maps platform.

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