Heuristic Tidal Advisor: An Innovative Algorithm for Tidal Prediction.

Dr S E Taylor. MD. Geomatix Ltd UK. Sep 2016

Abstract

The height of the tide is caused not only by the tide raising forces of the sun and moon, but also by meteorological conditions. This paper describes a computer algorithm which, unlike conventional astronomical tidal prediction, directly uses past tidal records to create predictions. The method inherently handles surging tides thereby assisting the harbourmaster and mariner in safely managing vessel operations. This paper describes the installation of the system and testing at Sharpness Docks.

Introduction

In practice, the height of the tide results from two main factors, an Astronomical Tide resulting from the gravitational tide raising-force of the sun and the moon, and a Meteorological Tide resulting from the effects of atmospheric pressure, wind and in some cases rain, for example where it affects fluvial flow.

The resulting tide can thus be described to a first approximation by the linear superposition of the effects of these two factors. The official tidal predictions from the national hydrographic offices only deal with the astronomical portion of the tide. Therefore, when adverse weather conditions prevail the tide, when compared to the official predictions, may arrive early or late; and also its height may undercut or exceed the predicted figures. Such deviations from the astronomical tide are generally referred to as tidal surges.

When a tide unexpectedly "undercuts" due to adverse meteorological conditions, a vessel approaching a dock may have to be turned away at the last minute, rather then risking it grounding on the lock gate sill.

During a period of approaching neap tides, when the effects of the sun and moon are tending to cancel, each successive high tide is lower and the access situation worsens since the vessel may not be able to access the harbour for many days.

This is particularly true at the entrance to Sharpness Dock, a tidal location which is particularly susceptible to such access problems as the tide is large, and there are also frequent discrepancies between the observed and predicted times and heights of the tide.

In some regions, such as in the UK North Sea, surge predictions are available using a hydrographic computer model [Ref 1] which takes into account the meteorological conditions. However, many regions in the world do not have the luxury of having access to such a facility and so there is a clear requirement for an alternative simpler approach.

This paper describes the development of a novel algorithm we call the "Heuristic Tidal Advisor" (HTA) which predicts the forthcoming tidal curve in a new way and which implicitly takes into account surge conditions.

The HTA algorithm produces predictions of total tide height without splitting the tide into surge and astronomical components; it has no requirement for harmonic constants, Doodson numbers or tidal force factors. Rather it relies upon the shape of the observed rising tidal curve and comparisons with the past tidal records to provide its predictions.

Using pattern recognition and curve fitting algorithms, the THA is able to produce a predicted tidal curve together with an estimate of confidence.

Typically heuristical predictions are possible up to 2 hours before the high water actually occurs, providing the harbourmaster with useful information, sufficiently in advance, to decide as to whether a vessel can safely approach and dock, or whether it must be turned away.

The system may also be of use in providing automated advanced warning of tidal flooding caused by meteorologically induced surges.

A discussion of the performance of the THA algorithm and its installation at Sharpness Dock is described where the tide rises and falls very quickly and is particularly susceptible to meteorologically induced surges.

Description

Development of the THA algorithm followed tidal analysis work at Sharpness Dock which has previously been described [Ref 2]. Although that work showed promising results it did not predict those unusual tides which made the management of vessels operations difficult.

We started with the commonsense notion that when a tide arrives early it will probably go on to peak early by a corresponding amount of time. A similar situation could be said to occur with tidal height, if it is higher than expected maybe the high tide will be higher than expected, although of course allowance must be made for the spring neap cycle.

These commonsense notions beg the question of what is meant by early, late or expected.

A formal mathematical way of framing the situation is to use a parametric plot of rate of height against rate of rise - this plot being similar to a Lissajous Figure.

Such a plot for the tide at Sharpness is shown in Figure 1, with the vertical axis being the tidal height and the horizontal axis being the rate of rise of the tide.

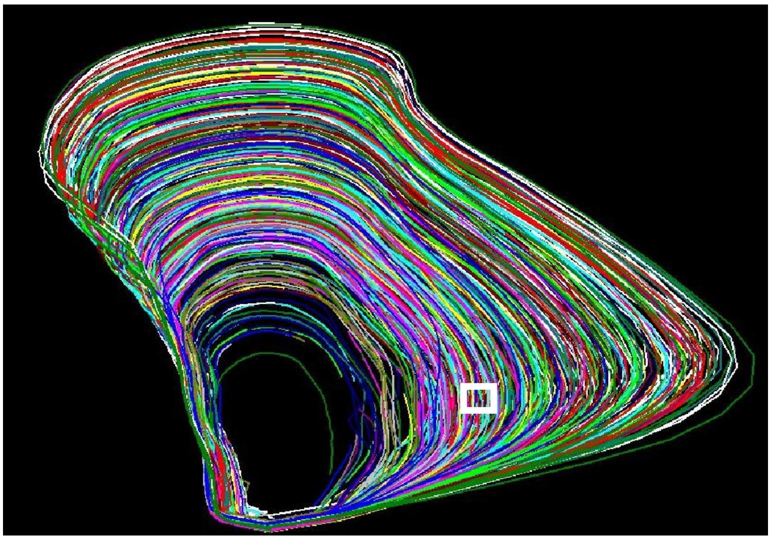


Figure 1: Parametric Plot of Sharpness Tide. H(t) v dH/dT

An incoming tide has a unique pair of values of 'height' and 'rate of rise' enabling a computer to look up the current situation on the plot of past tides. This provides a starting point for a search of past data, and from which the tidal graph can be obtained by following the curve around, in the above diagram in an anticlockwise direction up to its maximum value. Furthermore, one can start with a selection of nearby lines, each of which are traced out, and averaged. During investigations, this method was implemented by selecting all of the traces within a small square of sides $\Delta H(t)$ and $\Delta H'(t)$ a shown in Figure 1 where Δ represents a small but finite range of values. This method gave quite promising results with positive feedback from the pilots and harbourmaster regarding the reliability of the predictions.

However occasionally, a few times per year, the tidal predictions were unacceptably inaccurate. This can be seen upon close inspection of Figure 1 where occasionally a tide would "change gear" moving from a smaller loop to a larger one.

In order to correct for this we tried to introduce a measure of 'tidal acceleration' in a similar way to the use of the tidal 'rate of rise'.

A similar figure was used but with 3 dimensions and all tides were selected whose value fell within a small cube of sides $\Delta H(t) \times \Delta H'(t) \times \Delta H''(t)$.

It was further felt that enhancement to the method could be obtained by adding even more derivatives, essentially with each derivative being the next element of a Taylor Series Expansion.

$$f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \frac{f^{(3)}(a)}{3!}(x-a)^3 + \ldots + \frac{f^{(n)}(a)}{n!}(x-a)^n + \ldots.$$

However, it soon became apparent that, in practice, the higher derivatives could not be calculated sufficiently accurately for the higher terms of the Taylor Series Expansion. This was because a) the tidal data is actually a time series of measurements separated by small but finite times, b) there is noise due to the precision of each data reading c) there are random fluctuations in sea level and electrical noise. The accurate application of the Taylor Series Expansion requires that an accurate instantaneous derivatives are calculated.

It became apparent that, rather than attempting to calculate instantaneous derivatives from an inherently discrete and noisy signal, a pattern matching algorithm may be preferable; by comparing a portion of the shape of the discrete historical and incoming curves. Such a method, by comparing the general shape of the curves, should be roughly the equivalent to including those higher terms in the Taylor expansion, without actually having to calculate them.

A considerable amount of development work was carried out over a number of years to refine the algorithm which, not only has to handle large quantities of historical data taken at differing sample rates but also has to be extremely fast, so that it can carry out a match in real-time as tidal data comes in at 5 second intervals.

The algorithm which we developed we called the Heuristic Tidal Advisor or HTA for short.

Installation

The HTA algorithm was installed into data logging software which had already been supplied and installed at the Sharpness Dock by ourselves, Geomatix Ltd [Ref 3]. The support of the harbourmaster [Ref 4] was invaluable in accommodating the IT requirements.. A diagram of the setup is shown below. The system used a commercial unvented submersible tide gauge sensor with electronic pressure compensation. [Ref 5]

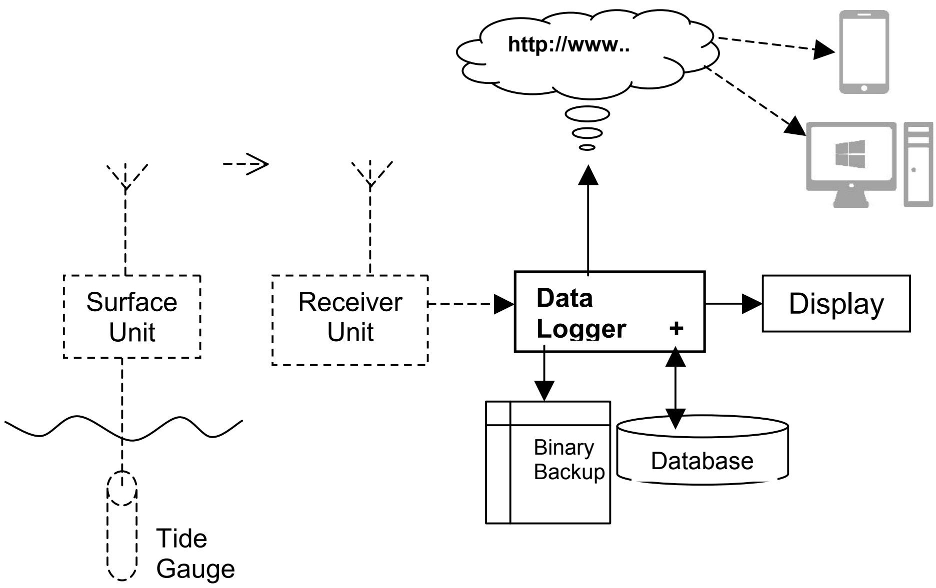


Figure 2 THA Installation

In practice, as experimentation continued, many slightly different versions of the algorithm were coded up and loaded into the system and a highly subjective value judgment was made regarding its accuracy and reliability. After some time it became clear that a more scientific method of testing each version of the changing algorithm was required.

Fortunately in the early days of this research project it had been decided to log all individual tidal data as it arrived from the tide sensor unit (at 5 second intervals) as well as logging the data in the more usual way in a database at 5 minute or 10 minute intervals. This real time input data had been stored within a binary data file for provenance and audit purposes.

This binary data subsequently proved very useful since, once we had gathered almost a years data at 5 second intervals, a new way opened up to carry out an accelerated form of automated algorithm testing. The 5 second tidal data was played back at an accelerated rate into the program as if it was originating from a tide gauge.

It then proved possible to run the algorithm in an faster way at around 300 times real-time, enabling testing of a year's real data within 24 hours. A further module was added which automatically compared the predicted height and time of high tide with the actual values and the values published by the HO. This greatly assisted the process of algorithm development as not only was the cyclic process accelerated considerably but there was also now an objective criteria in terms of accuracy. We were thus able to rapidly optimise the algorithm, resulting in a considerable improvement.

The system is currently installed and is being further evaluated in Sharpness Dock on the Severn Estuary in the UK. The predictions are relayed in graphical and text form via the internet and are available to pilots and the harbourmaster via smartphones, tablets and PC web-browsers. See Figure 3

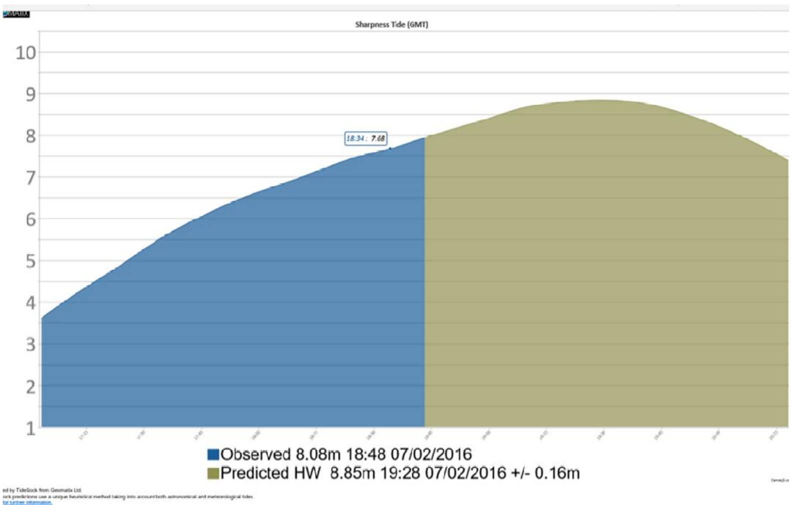


Figure 3. Web Graphical Output

The system is in regular use, advising pilots of the likelihood of the tide undercutting, surging or arriving late or early.

Results

The results of the tests of the HTA algorithm (as at 1 Sept 2016) are provided below, where each prediction was at one hour before each actual high tide for which valid data was available. On each run the following input parameters were used.

Tidal Input
Scan Duration: 07/07/2015 to 17/06/2015
Number of Tidal Readings Input: 720 at 5second intervals

Past Data
Tidal Record Duration: 01/01/2013 to 31/12/2014
Tidal Record Interval: 5 minutes

A summary table is shown below whilst scatter plots showing a visual comparison for each observed tide are shown as plots overleaf.

Statistic	***HTA Time Diff (minutes)***	***HO Time Diff (minutes)***	***HTA Height Diff (meters)***	***HO Height Diff (meters)***
Mean	-0.82	1.14	0.00	-0.06
Median	-0.49	-0.34	0.01	-0.04
Standard Deviation	6.13	9.46	0.18	0.26
Minimum	-19.01	-18.28	-0.60	-0.87
Maximum	20.96	39.17	0.68	0.58
Range	39.97	57.45	1.28	1.46
Tide Count	641	641	641	641

Table 1 Comparison between HTA & HO Predictions at ONE HOUR before HW.

It can be seen in Table 1 that by almost every measure including mean, Standard Deviation and range, the HTA predictions offer an improvement upon the HO predictions. Of particular significance is the greatly reduced range of time differences and range of height differences for HTA predictions compared to those from the HO.

Turning to the scatter plot of time predictions in Figure 4, the THA time prediction were generally within +/-10 minutes and occasionally within +/-20 minutes of actual high tide time, while the HO predictions vary from -20 to +40 minutes. Similarly the scatter plot of height predictions in Figure 5 shows the THA is generally within +/-0.2 metres and occasionally up to +/-0.6 metres out, while the HO predictions are generally within +/-0.4 metres but sometimes over +/-0.8 metres out.

Figure 6 shows the distribution of predicted tides with time, and shows a narrower distribution for THA than HO predictions, as does Figure 7 showing a similar plot for height distributions.

Figure 4
Scatter Plot Accuracy of Time Predictions: HO v HTA

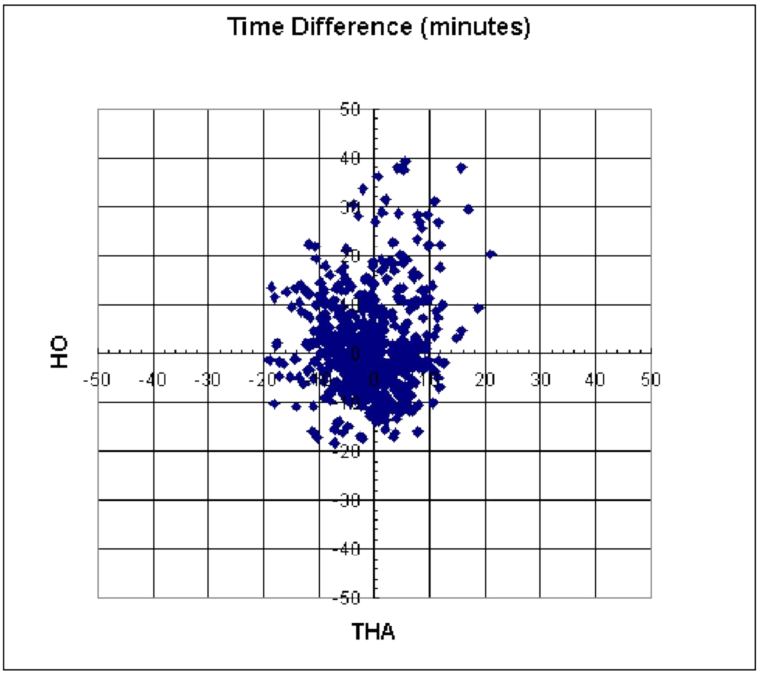
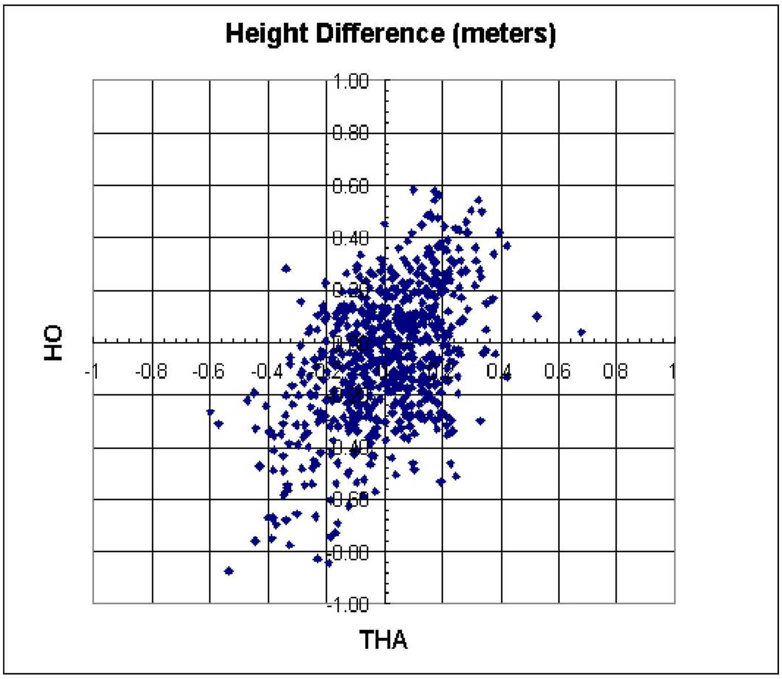


Figure 5



Accuracy of Height Predictions: HO v HTA

Figure 6
Number of Time Predictions v Time Range

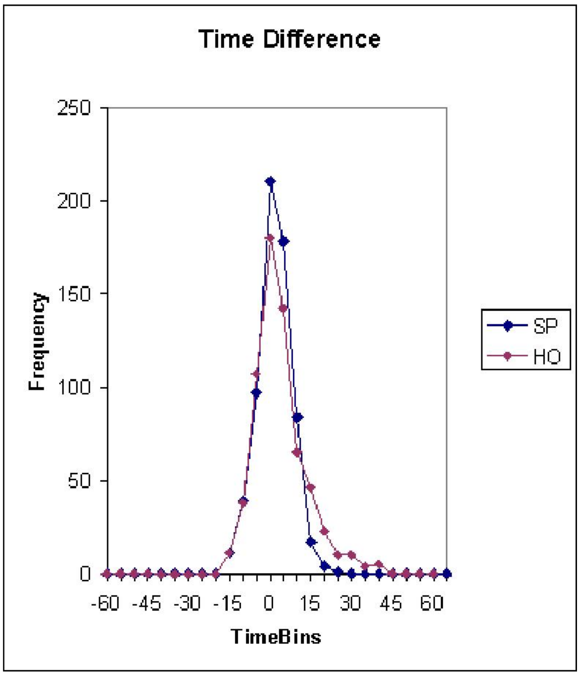
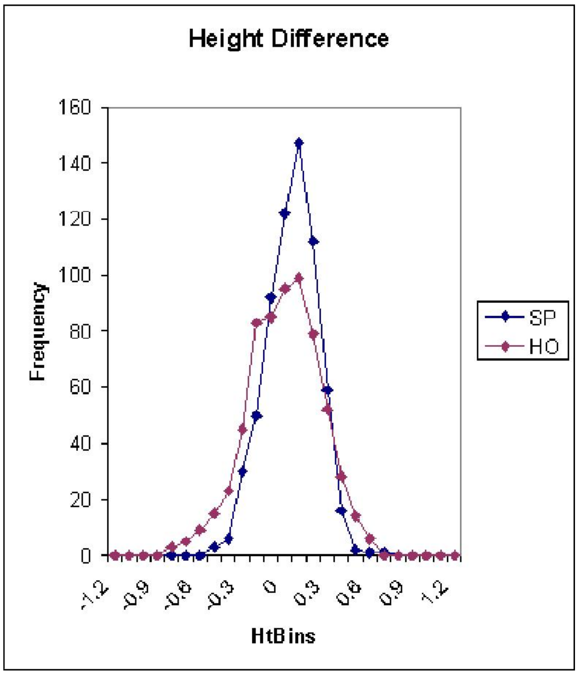


Figure 7
Number of Height Predictions v Height Range



Conclusion

The design, development and testing of a new tidal prediction algorithm, which we call the Heuristic Tidal Advisor (HTA) has been described.

During tests of around one year at the test site of Sharpness Dock, the HTA algorithm provided a significant improvement over HO predictions at one hour before HW.

While this may not seem so significant one has to bear in mind that at this location the tide rises from its minimum to maximum with 2 hours.

The unique advantage of the HTA algorithm is that it predicts the total tide, implicitly including the effects of tidal surges.

However, unlike conventional tidal prediction, the HTA will only predict the tide a few hours ahead.

The HTA algorithm therefore complements rather than replaces the harmonic tidal analysis and prediction method used by Hydrographic Offices worldwide.

Bearing in mind the extremely high rate of rise and large tidal range at the test site, it would be interesting to evaluate the system at a location which suffers from tidal surges but which has a more normal tide.

References

1. UK National Tidal Sea Level Facility, http://www.ntslf.org
2. Tidal Analysis & Prediction: Sharpness Dock on the upper reaches of the Severn Estuary, Dr S E Taylor Geomatix Ltd, UK. Marine Measurement Forum 2012.
3. TideSock Data Logger. Geomatix Ltd, http://www.geomatix.net
4. Mike Johnson, Sharpness Dock Harbourmaster, Gloucester Harbour Trustees. http://www.gloucesterharbourtrustees.org.uk
5. TideM8 as supplied by Ted Read of Ohmex Ltd. http://www.ohmex.com/