Feasibility of Velocity Measurements by a Drifter in the Yangon River

M.P.J. Janssen & R.J. de Koning

Delft University of Technology
m.p.j.janssen@student.tudelft.nl
r.j.dekoning@student.tudelft.nl

Abstract

Myanmar is dealing with a large data deficit, which is in contrast with the substantial need for it. The implementation of measuring techniques to obtain hydro- and morphodynamic data is an upcoming process. Measuring velocities can be valuable for calibrating models or giving estimates of sedimentation and erosion. An example of a measuring method is the use of a drifter, which is common for nearshore applications, but less for rivers. Therefore the feasibility of a drifter is tested in the Yangon River. The design includes amongst others drogues, which try to follow the governing velocity, and a GPS-tracker. This design was calibrated, where the number of drogues is adjusted to five. During the measurement campaign a flow meter was used to find the best fit for which depth the drifter measures its velocities, according to the weighted least squares error method. With this results, the values are scaled to a line of best fit. Subsequently the results are compared with a simulation, in which the already scaled results are adjusted to their respective direction. The average difference between simulation and measurements appeared to be 20%.

I. Introduction

The Ayeyarwady Delta plays an important role to water in Myanmar. The densely populated area benefits by means of cultivation of primarily rice and the ecosystem is suitable for mangroves to grow (United Nations, 2011).

On the contrary, the river system in the delta can cause and experience issues as well. During the monsoon period the large rivers are unable to accommodate the significant increased runoff, giving rise to floods. In the pre-monsoon and post-monsoon the water levels in the rivers become very low. Consequently, saline water from the Andaman Sea is able to protrude far into the main land, with salinization of agricultural lands as follow-up event (MIWRM, 2014). Furthermore, navigation encounters difficulties reaching ports, as a result of these low water levels and increased sedimentation. The latter is mainly a problem in the Yangon River, in which 90% of Myanmar's international marine trades takes place (Aung, 2013). The river runs from the mouth till the left river branch in Figure 1.

In order to solve these issues, understanding of the behaviour of the river system is required. Because of the economic importance of Yangon and its ports, insights in the occurrence of floods, salt intrusion and sedimentation in the area is paramount. These can be obtained from simulation models, which require accurate and reliable data.

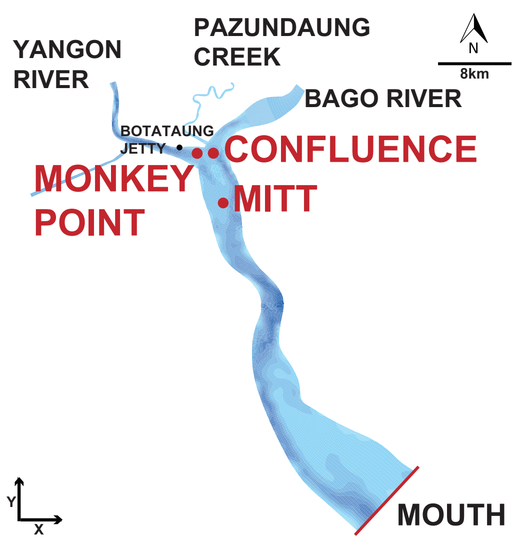

Figure 1: *Lower part of the Yangon River from left branch till mouth. Red dots are measuring locations.*

Myanmar is dealing with a large hydrological and morphological data deficit (Attema, 2013), due to several political disturbances. Additionally, the GDP in Myanmar is still low, despite the economy is growing (Trading Economics, 2003). This increased the interest in affordable measuring devices to improve data for Myanmar, but also other data poor environments. This might subsequently result in solutions for irrigation, sedimentation and erosion.

Water level is a common validation parameter in hydrodynamic models. The technique to measure it is relatively easy and cheap: a floating object can measure the level all day. On the other hand, velocities can provide a valuable indication for hydrodynamics as well. Measurements of velocities at different locations along a river branch can give estimations of streaming patterns (Wagner & Mueller, 2000), providing insights in governing river processes and expected erosion locations. Additionally, velocities are the main indicator for the classification of flood or ebb dominated system (Bosboom & Stive, 2013). Examples of velocities measuring devices are the Acoustic Doppler Current Profiler (ADCP), the current meter and drifters. The ADCP is able to measure velocities while moving, ideally for large-scale discharge measurements (Teledyne, 2015). The current meter is useful for accurate small-scale velocities measurements. The use of drifters is often used for nearshore processes, to measure amongst others flow patterns (Johnson et al., 2003). However, the application of drifters to accurately measure velocities is less common. If a large drifter campaign is able to measure velocities along a river branch within a certain accuracy range, it can be valuable for large data acquisitions in countries like Myanmar. Especially when the cost of a drifter is considerably lower than than an ADCP. Therefore this research focusses on the feasibility of a riverine drifter application under Myanmar conditions. The application and validity of one drifter design is presented in this research, but also the usage of multiple drifters as part of a large-scale measurement campaign will be discussed.

II. Materials and Methods

Design

The drifter for the river velocity measurements consists of two primary components: the drifting part and the submerged part (Figure 2). The integrated design needs to be reasonably priced according to local standards.

The drifting part's purpose is to remain GPS connection. This implies that it should have sufficient drifting capacity, because a submerged GPS will lose signal. The applied G-Porter GP-102+ is able to measure velocities up to an accuracy of ± 0.1 m/s (Canmore Co., 2015). The device is sealed in an AQ108 waterproof bag (Aquapac, 2015). The waterproof GPS was placed in a cut-in-half jug. Water intake by the jug should be avoided as much as possible in order to prevent the drifting part from submerging.

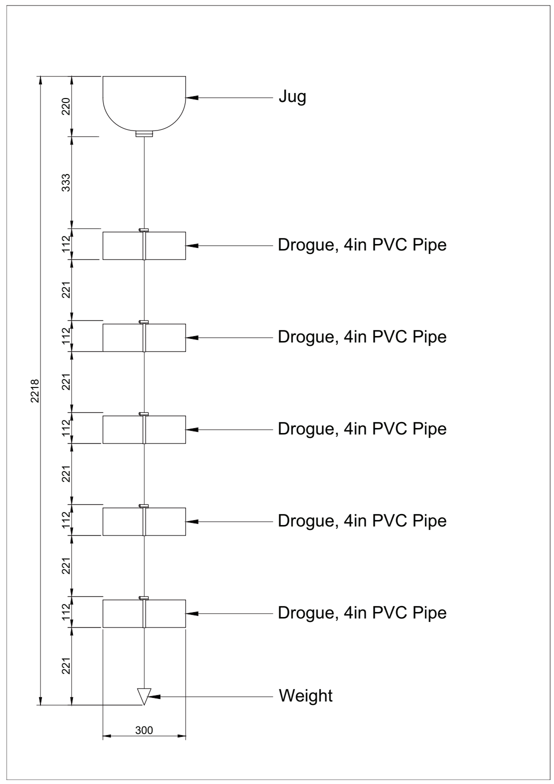

Figure 2: *Drifter design*

According to Murthy (1974) the effect of wind may not be neglected in the drifter design. It is an effect which needs to be excluded as much as possible in order to measure the streaming due to tide and river discharge. The materials responsible for this, the drogues, are located under the drifter. The drogues, in combination with an added weight, which has the function of keeping the drogues immersed, form the submerged part. In order for the water to be able to flow through the drogues, these objects are hollow and open. Strong material for the drogues (PVC) was chosen, because high velocities can be observed in the Yangon River (Nelson, 2000). The total number of drogues and thus the length of the drifter was found with calibration, given in Section III.

Calibration

Initially three drogues were added to the drifter. The number of applied drogues most likely determines the drag and the depth at which is measured. The underlying theory is that more drogues provide more surface for the streaming to exert on. In this way the effect of the wind, which takes place at the surface, is filtered out even more. Throughout calibration the number of drogues is adjusted. The total length of the drifter with three drogues is around 150 cm and an additional drogue corresponds with an increase of 30 cm (Figure 2). The Valeport Model 002 Flow Meter served as calibration tool and was submerged around 50 cm below surface level. Its accuracy is $\pm$2.5% for measurements above 0.5 m/s and $\pm$0.01 m/s for results under 0.5 m/s (Valeport, 2015).

The calibration was conducted on 24 October 2015 at Botataung Jetty (16°76'58"N 96°17'23"E), see Figure 1. Indoor measurements are not possible, because the GPS only receives signal if it is used outside. The obtained values from both flow meter as drifter are assumed to be not representative for the measurements on the Yangon River, because they were conducted from a jetty. This means the streaming is influenced too much by local conditions, such as reflection from the jetty and river banks. However, both measuring techniques are applied in the same conditions and at the same moment. Therefore, the method is acceptable for calibration.

The G-Porter GP-102 provides at given time intervals a location of the drifter (Figure 3). From these space and time variables, the velocity magnitude is determined by the device. This implies that only the resultant velocity is calculated, but not the individual velocities in horizontal and vertical, respectively x- and y-direction. Next to that, the GPS-data needed to be adjusted as follows. First the intervals of the release and the pulling back of the drifter were filtered out. Next, the remaining results were averaged and a standard deviation was assigned. Finally, the averaged result of the GPS and the values of the flow meter were compared for different number of drogues (Figure 4). It is thus assumed that both measure the same direction.

Measurements

The actual measurements were all conducted on 25 October 2015 on three different locations: around Monkey Point (16°76'17"N 96°19'07"E), at the confluence of the Yangon River, Pazundaung Creek and Bago River (16°75'98"N 96°20'47"E) and around MITT, the Myanmar International Terminals Thilawa (16°72'02"N 96°21'10"E), as shown in Figure 1.

A representation of at which depth the drifter resembles the velocity the best needed to be found first. This can be identified as a calibration process, but because this is assumed to be influenced by the depth, the outcome is area specific and not only depends on the design of the drifter. Likewise as in the calibration, the flow meter was used for analyzing the drifter results. This was done at 3ft, 6ft, 12ft, 18ft, 21ft and 30ft depth. The averaged GPS values were compared with the flow meter results for the different depths. A regression line was assigned according to the weighted least squares error method, in which the weight is given by $\mathrm{w_i} = 1/\sigma_\mathrm{i}^2$ where σ_i represents the standard deviation for measurement point i. This implies that more reliable data points are considered to influence the regression line more. The depth dependent lines were compared by calculating the error to a line of best fit (Figure 5). The depth for which the results gave the least error was assigned to be representative. The results from the drifter measurements were scaled accordingly, given as $\mathrm{V_{scaled}}$, for their respective direction.

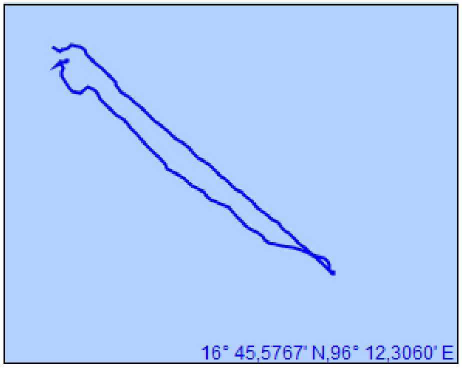

Figure 3: *Ouput G-Porter GP-102 (Canmore Co., 2015)*

Comparison with model

The obtained results were analysed with reference values from a hydrodynamic model (Janssen & de Koning, 2015). This model can give the magnitude of velocities in x- and y-direction or the separate velocities for these directions. The best method would be to compare the drifter results with the magnitude of both velocities. However, the model would give merely positive values, according to:

$$\mathrm{V} = \sqrt{\mathrm{V_x^2} + \mathrm{V_y^2}} \tag{1}$$

Therefore the seperate velocities are reviewed. First the dominant direction in the signal is determined. This depends on the orientation of the river branch, the interest in the occuring processes and the main direction the drifter is travelling. Due to the irregular path the drifter travels during a measurement (Figure 3), the signal contains both velocities in x- and y-direction. Therefore an adjustment need to be made on the already scaled values. This is calculated by taking the vector in the respective direction for each data point i:

$$\mathrm{V_{x,i}} = \mathrm{V_{scaled,i}} \cdot \cos(\theta_\mathrm{i}) \tag{2}$$

$$\mathrm{V_{y,i}} = \mathrm{V_{scaled,i}} \cdot \sin(\theta_\mathrm{i}) \tag{3}$$

In here, $\mathrm{V_{scaled,i}}$ is already determined from the flow meter scaling. The angle between the path of the drifter in x- and y-direction for each data point, is calculated by:

$$\theta_\mathrm{i} = \arctan\left(\frac{\mathrm{d_{y,i}}}{\mathrm{d_{x,i}}}\right) \tag{4}$$

in which $\mathrm{d_{x,i}}$ and $\mathrm{d_{y,i}}$ are the distances the drifter travelled in respectively x- and y-direction. These are determined from the coordinates of the release and retrieval of the drifter according to the Haversine equation (Sinnott, 1984). This is justified, because the path the drifter travelled appeared to be more or less straight (Figure 3). For Monkey Point the x-direction is assumed to be dominant, while for Confluence and MITT this is the y-direction.

III. Results

Design

The focus in this research is on an affordable drifter design. The total costs of the drifter are given in Table 1. The costs under 'others' include amongst others the weight (Figure 2) and the wire to retrieve the drifter. It can be observed that the costs of GPS dominate the total costs, which was necessary to reduce the inaccuracy of the drifter results. The drifter is low-priced compared to the flow meter and ADCP, which cost around \$8.000 (Valeport, 2015) and \$2.000-\$18.000 (USBR, 2015) repectively. This increases the implementation options in Myanmar. Also the drifter has the advantage of, in case it is handled well, to give pattern and streaming information. It is however less applicable for large scale discharge measurements, compared to the ADCP, which is able to measure velocity profiles over depth.

Table 1: *Drifter costs*

Material	Costs (USD)
GPS	80
Drogues	10
Waterproof bags	35
Others	10
Total	135

The drifter design was able to resist the strong currents. However, the jug filled with water and subsequently went to the bottom. Extra drifting capacity and capsize preventing material (life buoy) was added to the drifting part. This is assumed to be partly at the expense of the capability to measure stream velocity and filter out the wind velocity.

Calibration

The mentioned theory that more drogues would lead to a better representation of the actual governing velocity was tested in the calibration. The results in Figure 4 seem to confirm the theory. It can also be observed that all drifter results are larger than the flow meter values. Possible explanations are given in Section IV.

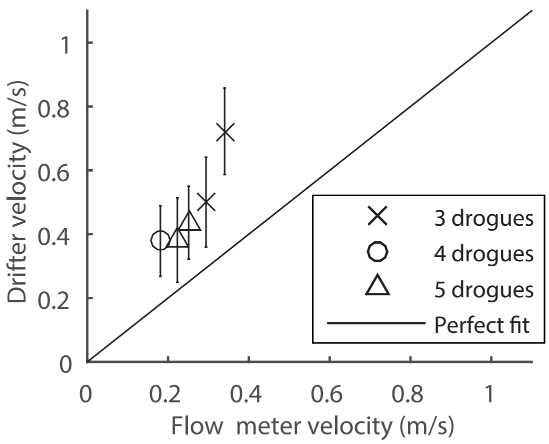

Figure 4: *Calibration by adjusting number of drogues*

From Figure 4 it can be observed that the transition from four to five drogues is not really significant anymore. Next to that, the length with five drogues is already 210 cm, which decreases the handling of the drifter. For these reasons no more drogues were added and a downscaling of future results would be applied. Also the standard deviation of the data points is included in Figure 4, which are more or less similar for the different data points.

Measurements

The mentioned method of finding a representative depth (Section II) results in depth dependent fitting lines, is based on the weighted least squares error. The correlation between a line of best fit and the 18ft, 21ft and 30ft appeared to be too small. Therefore those lines are left out in the subsequent calculation of the errors between the line of best fit and depth dependant fit. The surface, 3ft, 6ft and 12 ft lines are compared with the line of best fit (Figure 5).

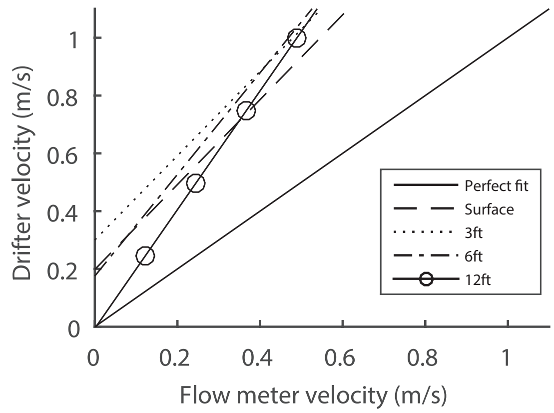

Figure 5: *Comparison weighted fits*

The surface line gives the best fit for the range between the lowest and highest value observed that day. This implies that the measurements are scaled according to the surface fit line onto the line of best fit. Since all drifter results were higher than the flow meter results, this scaling entails a downscaling of results (Table 2).

Table 2: *Velocity scaling*

Location	V_{drift} (m/s)	V_{scaled} (m/s)	$\Delta V1$ (%)
Monkey Point	0.83	0.43	48
Monkey Point	1.08	0.60	44
Monkey Point	0.79	0.40	49
Confluence	−0.69	−0.34	51
Confluence	−0.56	−0.25	56
Confluence	−0.44	−0.17	62
Confluence	−0.43	−0.16	63
Confluence	0.66	0.31	53
MITT	0.88	0.46	47
MITT	0.74	0.37	50

The adjusted values seems to deviate significant from the original drifter velocities. However, the individual differences does not differ much from each other. So despite the large differences in velocity, the applied scaling method is a justification due to the consistency of the differences.

Comparison with model

In the comparison between drifter and simulation the slack water observation during the measurements was important. Namely, one measurement was going seawards, while the next, conducted a few minutes later on the same location, was going landwards. This was at Confluence around 10:30 am. It means that a slack water was present from low to high water. The simulation output can be adjusted to this position. The same adjustment was applied on the two other locations.

The result of the scaled velocities with the hydrodynamic model is given in (Figure 6). For Monkey Point the simulation is in x-direction and for Confluence and MITT this is in y-direction.

Drifter and adjusted drifter points can be observed in the figure, which do not differ considerably from each other for Monkey Point. For Confluence and (less for) MITT the adjustments are more significant (Table 3), probably because there are more different directional velocities present at this point. The match between simulation and measurements seems to be reasonably good (Figure 6), with an average difference of 20%. The still present differences can be due to the measurements or the simulation, elaborated in Section IV.

Table 3: *Velocity adjustment*

Location	V_{scaled} (m/s)	$V_{adjusted}$ (m/s)	$\Delta V2$ (%)
Monkey Point	0.43	0.41	4
Monkey Point	0.60	0.57	5
Monkey Point	0.40	0.39	2
Confluence	-0.34	-0.22	34
Confluence	-0.25	-0.17	32
Confluence	-0.17	-0.10	38
Confluence	-0.16	-0.07	53
Confluence	0.31	0.30	4
MITT	0.46	0.29	37
MITT	0.37	0.36	3

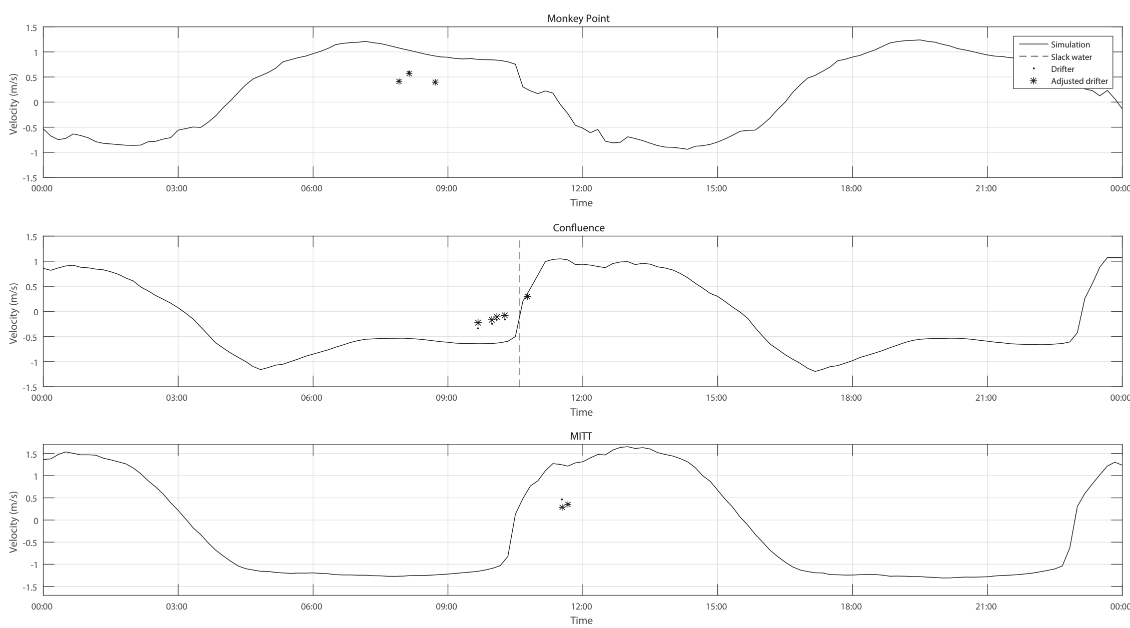

Figure 6: *Simulation and measurements for the three locations.*

IV. Discussion

Differences measurements

Some considerations made in the design, calibration and measurements can be controversial. Improvements in these phases are possible for further research. The differences in simulation and measurements can be due to the simulation, which is not part of this research, or due to the measurements. For the latter, explanations are given below.

In this research five drogues were used, which covers a relatively small depth. Increasing the number and dimensions of the drogues most likely increases the drag, filter the wind effects and decreases the velocity of the drifter. Also more calibration is recommended, in order to obtain a just amount of drogues.

A second explanation for the higher velocities of the drifter might be the difference in reference frame of both drifter and flow meter. The drifter is measuring in a Langrangian frame of reference, which means that the measurement is following the particles, while the flow meter measures in an Eulerian reference frame, implying a fixed point measurement. In case of wave movement the fixed point measurement lacks an additional velocity, the Stokes' drift, compared to the drifter (Stokes, 1847). This difference was assumed to be neglectable in this research, because the measurements were conducted 40km upstream from the mouth and thus the wave motions are considered to be small. Due to the large time scale of a tidal wave, also the Stokes' drift of this motion is insignificant. A better understanding of these occurences in the local conditions might give a better correlation for both measurements.

Thirdly, the velocity profile in the river can be an explanation. Namely, due to the friction exerted by the bottom on the flow, the velocity profile is nonlinear. The Yangon River can be considered as shallow (5-15m). For flow in shallow areas the velocity gradient is often assumed to be logarithmic. The representative mean velocity in such profiles can be found at $\pm$60% of the depth under surface level and can be considered as the depth averaged velocity (Verhagen, 2015). This velocity is the output in 2D hydrodynamic simulations. However, as a result of the submerged length of the drifter, the drogues cover around 10-30% of the total depth and might thus overestimate the actual velocity. On the other hand, the flow meter is submerged at 50 cm below surface level, so it should also overestimate the representative velocities. Therefore a logical conclusion could be that the drogues do not correspond well with the representing depth. So it is stressed here that the depth at which the submerged part is located, does not necessarily correspond with the velocity at that point. On the contrary, the scaled and adjusted velocity points are often lower than the simulated values (Figure 6), which contradicts with the theory above. A better insight is recommended by measuring velocities over depth more accurately.

Finally, both the G-Porter GPS as the Valeport flow meter have a uncertainty, which this research did not take into account. An overestimation of the GPS and an underestimation of the flow meter are possible explanations for the higher drifter values.

Calibration

The calibration was conducted from a stationairy point, a jetty. The reflection of the jetty and bank can disturb the measurements by adding velocities perpendicular to the drifter direction. The assumption made that the flow meter is dealing with the same conditions, can be considered roughly, because the flow meter can be less sensitive for these disturbances. Testing and calibrating the drifter in a flume is recommended, because the actual velocities can be determined more accurate and less additional velocities are present. Occuring problem might be the losing signal of the GPS in case of indoor measuring facilities.

The results of the measurements only apply for the local conditions at the 3 locations present that day, because of the scaling with the current meter. The differences between drifter velocity and scaled velocity are not significant and are thus a just method to obtain depth calibrated results. However, when using the drifter under different conditions, less scaling efforts might be beneficial. In order to accomplish this a better representation of the velocities by the drogues need to be found.

Practical

In the processing of the results, the location of slack water is very useful in order to shift the simulation to the right position. It is thus recommended to catch a slack water in the measurements.

If time and budget are available multiple drifter releases will give a better understanding of the deviation from actual velocities. A more founded statistical analyses can be performed, which improves the adjusted velocities.

During the measurements some practical issues with the drifter were encountered. It is stressed that the function of the drifter is focused on river velocity measurements. One problem occurring was that the open jug causes the drifter to catch water, immerse and therefore make it very hard to retrieve it again. Adding more drifting capacity or a closed jug solved the problem. However, floating objects can be influenced by the wind and thus the results. Furthermore a closed jug might distord the GPS signal. Therefore a balance needs to be found for the floating capacity.

The feasibility of a drifter design also includes the future use of these kind of affordable measuring techniques. This also means that local institutions, universities and research companies need to see potential in the design. Direct participation of the involved parties was requested in order to obtain the interest of the different stakeholders. According to students of Myanmar Maritime University (MMU) more field work and equipment design would improve their general skill set as future engineers. A combination of designing a drifter and joining in field trips will improve this. Next to that, awareness about feasibility of affordable measuring techniques can result into better data acquisition investments.

V. Conclusion

This research has shown that whether the application of a riverine drifter in Myanmar is feasible, depends on several factors. Concerning the design of the drifter, this implied a reasonably priced design, made of local available materials and applicable in the wild Yangon River. The costs of the drifter are compared with a flow meter and ADCP. It appears that the drifter is better affordable due to the local obtained materials (except for the GPS and watertight bag). Also in case of multiple drifters as part of a measuring campaign, the drifter is cost efficient. However, during the measurements the floating capacity of the drifter failed, leading to added materials to the drifter, which increases the influence of the wind on the measurements.

In this research the flow meter was assumed to be the most accurate, because it is calibrated in advance, while the drifter was designed with local materials. Therefore the drifter was calibrated concerning the design and governing depth with the flow meter. This resulted in five drogues, which is wind excluding material, constantly submerged under the GPS. Because the accuracy of the flow meter is assumed to be sufficient, the measurements of the drifter are scaled accordingly to the output of the flow meter results. At which depth the drifter resembles the velocity the best, needed to be found first. This was done by measuring the velocity at different depths using the flow meter and compare those with the drifter results by using the weighted least squares error method. The difference between the initial values of the drifter and the flow meter can be allocated to non-linear velocity distribution, local conditions and inaccuracies of the measuring device.

Furthermore, the scaled results are compared with a model simulation of the Yangon River. The drifter values first needed an adjustment for their dominant direction in order to be able to compare the model output with the drifter values. The difference between both appeared to be around 20%, which can be due to inaccuracies of the measurements and the flaws of the model.

Three different velocity outputs were thus obtained: drifter, flow meter and model output. A good validity of the drifter output can result in large-scale data acquisition. A certain caution is stressed here concerning completely relying on one measuring device. All three output deviated significant and the true occurring velocity should be determined, taking into account the flaws, uncertainties and inaccuracies of the measuring devices and simulation models. In this research, a possible method is described for the justification of handling with these kind of inaccuracies. If this is done correctly, the usage of multiple drifters to measure velocities can be a viable option in (data-)poor countries. The reason for this is the affordable price, the ease to built drifters and, if calibrated correct, the possible large-scale data acquisition. Finally, it is mentioned that the focus in this research was on the measurements of velocities by a drifter. The usage of determining flowing patterns is thus an additional advantage of the drifter.

VI. Acknowledgement

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