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Fully Integrated Unmanned Multipurpose Transporter for Dengue Control in Rough Terrain and Shallow Water Application

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Abstract: Unmanned Multipurpose Transporter (UMT) is a transporter to transport an object or device to the targeted/intended point. In this project, the transporter is customized to mobilize Dengue Fighting Capsule (DFC), which is a device meant for controlling dengue mosquito population. The function of DFC is to provide a comfortable water bedding for the dengue mosquito to lay its egg and subsequently, the eggs will be shocked by using the electrical current before pouring them on a layer of dry sand. In this way, DFC eliminates the egg before it hatches into full grown next-in-line carrier of dengue virus. Secondly, having the eggs on a layer of dry sand will further decreases the chances of the eggs from hatching. Often, the mosquitoes breading area is normally located at difficult to reach or unreachable places for example, gaps formed underneath the buildings due to residing of the soft soil over times, in the stagnant open pools of water or in both cases. In this project, we aim at developing a prototype of transporter to transport the DFC that is able to overcome all the challenges such as stagnant water pools, rough topology of ground and others. Beside physical built-up challenges, stability and anchoring in water by the transporter will also be studied. Deep understanding is required for the design and development of UMT as it involves multidisciplinary areas in engineering and technology.

Keywords: Integrated Unmanned Multipurpose Transporter, dengue fighting capsule (DFC), prototype, stability, mosquito population control.

I. INTRODUCTION

Throughout the whole world, roughly 2.5 billion people are at risk by infection of dengue virus and estimated 975 million of those are living in urban or rural areas [1, 2]. High risk continents such as the countries in Southeast Asia, the Pacific and the Latin Americas are at high risks. Locally in Sibu, which is located in the state of Sarawak, it has been reported that there is two to three fold of increase of reported dengue cases up to date. The current way of solving dengue problem is by fogging. This method involves spraying gas/vapour chemicals containing Natural Pyrethrins dual-synergized with Piperonyl Butoxide and MGK 264 chemicals intended to kill adult mosquitoes. The problem with fogging will cause an awful odour around the sprayed area for a certain period of time. Although it is effective for large surface area but its effect is only temporary. Moreover, fogging only kills the adult mosquitoes and not the larvae [3].

Dengue Fighting Capsule (DFC) is a device intended to fight the concurrent problem that we are currently facing in Sibu. The working principle of DFC is to provide comfortable water bedding for the dengue mosquito to breed on and subsequently destroy or eliminate the eggs before they hatch into full grown next-in-line carriers of dengue virus. Fig. 1 shows an conceptual design of a DFC device. There is a need to transport the DFC to its destination point, overcoming the rough terrain caused by residing of soils alongside with its topology factor and often, passing/bump into shallow pools of water. The designed and developed UMT shall be able to successfully and effectively transport DFC as well as to overcome the problems/conditions mentioned above.

Fig 1: Artist Impression of a Dengue Fighting Capsule (DFC) with intended dimension in centimeters range, 6 cm height and 3 cm in width. Water bedding consists of a crystal clear water which provides a good environment for the mosquito to lay its egg while attracted by a suitable chemical. Underneath the water bedding, there is a dry layer of sand capped by microsieve to hold the layer. The bottom part of DFC is the resevior where the water will be repump to the water bedding.

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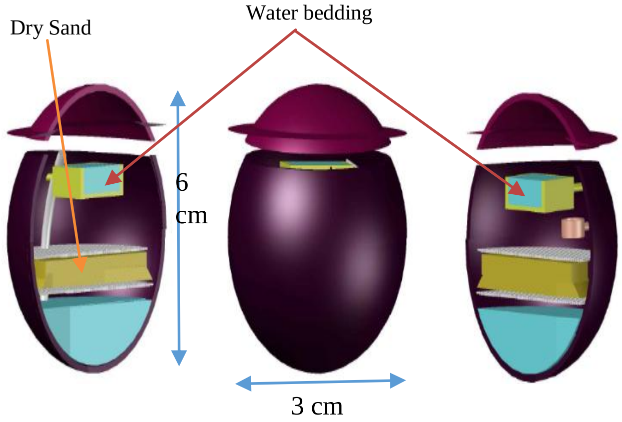

II. LITERATURE REVIEW

This section reviews on the techniques used in the past studies to design and develop a UMT prototype, stability studies and anchoring in shallow water. Development of unmanned ground vehicles (UGV) is not covered as the built-up is big in this paper. Most of the UGV reported in the literature are focusing on military usage, search and rescue and mine or explosive clearances [4]. However, the techniques used and implemented in the development of UGV could be further explored and used for designing and developing of the UMT. Three techniques hereby are to be reviewed extensively.

Adaptive technique is referring to the ability to maintain its current position by adapting it's built up structure regardless of any disturbances or interference. In this case, this technique refers to a joint shaft that controls the orientation of the structure. This enables the skeletal body to be flexible to disturbances for example rough topology. The advantage of this technique is that the movement of the drive shaft is independent of one another.

One example of adaptive technique is the independent rear wheel drives as shown in Figure 2, which was done by Hrbáček et al. and Campion et al. [5, 6]. In their experiment, the group developed a four-wheel structure which is a non-holonomic dynamic system so it could adapt to the uneven terrain, steering and independent rear drive unit. Kelly et al. also demonstrated similar findings as presented by Hrbáček et al. and Campion et al. [7]. In her experiment, a drive shaft is built in the transporter that carried the solar panel within the four-wheel structure. The function of the drive shaft is to connect the front to the back wheels. The reason for this design is to ensure that the rotation of the wheels is independent and able to move on uneven terrain. This adaptive technique enable the object to move stably on the rough surfaces. It is also equipped with motors used to rotate the four-wheel for movements which is controlled by a remote control.

Another example of the adaptive technique in mobile platform wheel mechanism is reviewed in this project was done by Nakajima et al. [8]. In their experiment, the four-wheel mobile platform, named RT-Rover's was able to move on rough terrain surfaces by stabilizing the platform on top of the transporter in the original position. This mechanism is mostly used in locomotive machineries. With four active wheels and five active shafts, it imitates the function of a leg as well as supporting the transporter. This system can detect different height of floors and adjust the movement of the wheels according to the height of the floor. Besides that, this particular technique is utilized by a robot that is used to carry an object or a person. However, the device can only be controlled by the person who is sitting on top of the platform. All the wheels are able to move around on their own and independent of one another's movement. According to Grand et al. and Reid et al. experiments, the idea of position and posture parameters were also demonstrated in another differential kinematic control of wheel-legged to provide high stability platform and able to move on rough terrain surfaces [9, 10].

Sensor is a component that senses and transduces the input signal to a readable signal as the output. There are different types of sensors available in the market namely, accelerometer, motion, infrared photoelectric and others. The sensing process is an energy conversion matter. It transports the signal into an output to enable the motor or device to work.

One example of the autonomous robot employing sensors/sensing technique was used by Jia et al. [11]. In their experiment, it was found that this technique used three basic categories of principles that include openness which is important to support the addition of new software modules as well as new hardware to a system. Second principle is abstraction which refers to abstraction of hardware, as hardware is generally subject to changes and lastly is the modularity for software design. The aim is to have reusable programming and reasonable design. This technique uses the Infrared (IR) photoelectric sensor to sense the reference line. Then, the sensor will follow the command by the microcontroller as mentioned by Bajestani et al. [12]. According to Lv et al., in the situation when IR sensor moves out of the line, the microcontroller will function faster to improve system reliability and accuracy in order to receive

reflection light [13]. The IR sensor can be converted into output signal voltage hence, feedback the corrective signal to microcontroller.
Second example of the self-balancing sensors/sensing is reviewed by Sundin et al. [14]. It is discovered that this technique was able to balance itself with the help of accelerometer sensor and two wheels controlled by the motor. The concept of construction of this technique is based on pendulum that is usually mounted on a cart. Although in Arvidsson and Grepl et al. experiment shared the similar finding as Sundin et al, at the same time, they demonstrated another idea of balancing which is when a person stands and moves on the self-balancing device, the device would move alongside with him [15, 16]. This enable the platform, to carry a small load and move accordingly to the sensors. In this case, three-axis accelerometer is used to measure the acceleration in all directions (X, Y and Z). Whenever, the platform encounter unstable situation while moving, the accelerometer sensor will detect the deviation in all x, y, z axes. This is translated into an increase of acceleration thus, it would activate the motor to stabilize the platform.
The concept of wheel-legged technique originated from an animal with four legs. Wheel-legged technique is designed for multiple degrees of freedom in movement. Those technique can either use leg or wheel or both depending on the situation or environment. When the wheel is used, it can move faster on smooth surface however, the wheel cannot be utilized on peak soil area. Hence, in the situation where there are peak and muddy soils, the wheel-legged technique can be used.
One of the examples of the wheel-legged technique (Rocky 7 Mars Rover) is reviewed in this project. It was done by Volpe et al. [17]. In their experiment, this technique was built for outdoor use on rough terrain surfaces such as on soil and rocks. Rocky 7 Mars Rover moves around with six of its wheels with the maximum speed of 20 cm per second. This robot is primarily powered by a 48W power source and secondarily with solar panel as a backup supply supported by an auto-positioning by a solar panel according to sunlight to maximize the energy conversion. This first highly intelligent robot of its size was been sent to Mars to test on all of its functionalities. Other than that, this mobile robot was used to collect scientific data and to capture pictures to be sent back earth every 26 months. In Iagnemma et al. and Matthies et al.'s experiment, a similar concept technique was used to assist the robot to move on rough terrain surfaces [18, 19]. Rocky 7 is controlled by accelerometer sensors that enable it to fully utilize degrees-of-freedom (DOFs) for stability purposes. The joint axis between the two tyres and platform could move 10 cm towards the ground. The wheel leg axis on the other hand is flexible and able to move up to 45◦ maximum.
Another example of wheel-legged technique is mantis hybrid leg-wheeled reported by Bruzzone, Tadakuma and Lin et al. [20-22]. In their experiment, they found out that this technique enables the robot to perform step-climb and to move on uneven terrain. This technique could justify the geometric and do motion planning on the static stability to climb and move. The idea of climbing and move on an uneven terrain are demonstrated. This technique has two interchangeable modes of operation either in the wheel or legged mode. Depending on the ground topology, this technique is able to operate independently either in the wheel or legged modes. This is desirable in this project. All the techniques were reported to be able to function well indoor and outdoor [20-22].
One of the conditions for the above mentioned technique to work well is the type of tire used. Typically a bigger and coarse tire are needed so that the robot can move on the sandy and rock surfaces due to its larger surface and gripping area. The suitable tire pressures to work on rough or soft soil surfaces from the literature is found to be 100 psi [23].

III. UMT DEVICE PROTOTYPING

There are two phases in the prototype design where the first phase is on the developing the prototype design while the second phase is on the circuit design and interfaces. The purpose of UMT is to transport the DFC on the ground and over/in shallow water. When UMT detects unstable position, the accelerometer sensor will send a signal to the servo to correct the position of the platform making it stable. Besides, UMT has the capability to (i) Move stably on rocky surface, (ii) Move stably on peak soil surface, (iii) Move stably from ground to water surface and (iv) Navigate on water surface and anchoring at a static position while in the water.
Balancing platform is crucial in this project. The purpose of building this balancing platform is to keep DFC device placed on top of platform. So it will not fall down during the transporting process. The bottom part of the platform will be attached to the transporter. As small volume of water is required for operation of DFC. Therefore, it is crucial to stay immobile as to prevent water leakage while transporting. To detect any movement/tilt, an accelerometer is used in this project. The accelerometer detects the unbalanced surface and sends out signal to microcontroller. The microcontroller will then activate two outputs of the servo motor to perform balancing. The idea of this design comes from the wheel-leg robot where the four wheels are used to keep the balance of the robot. Similar concept is applied to this project. This design was drawn using the AUTOCAD 3D software. The nominal designed dimension of the platform and DFC device is 14 cm length, 17 cm width and 15 cm of height. This design can be fitted onto the transporter. In designing this balancing platform, each of parts were separately designed and printed as per explain part by part in Figure 4.3 to

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4.6. On the top part of the balancing platform, there is a bowl-shaped container attached to it. The surface of the container should be appropriate in order to hold the DFC/object. Fig. 2 shows fully functional UMT device with balancing platform.

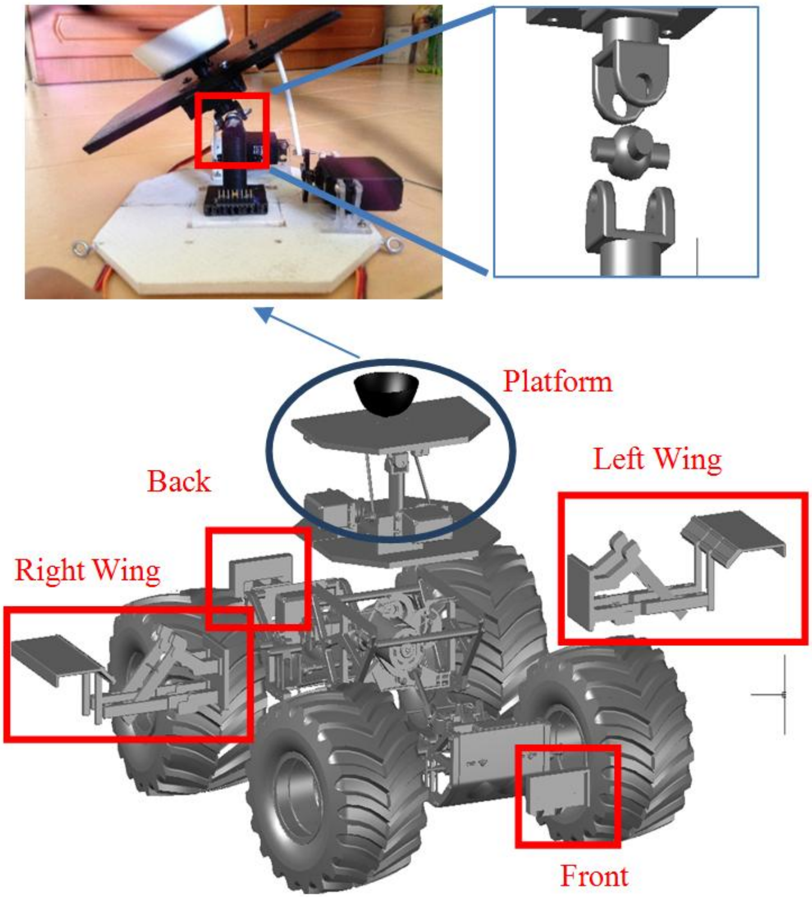

Fig. 2: Fully functional UMT device with balancing platform with universal ball joint is used to connect the top to the bottom part. The purpose of using the ball joint is so that movement from all angles could be accommodated.

From Fig. 2, it can be seen from the figure that the transporter is connected to the transporter by two servo motors. The main function of the two servo motors is to control and adjust the movement of the top part of the platform through a shaft. The DFC device will be placed on the platform. The stability of the device is determined by the platform when it moves around. Hence, in the case of instability is detected, the accelerometer sensor will be activated, thus initiating the movement of the two servo motors on the bottom part of the platform. The servo motors will adjust the movement in the x and y axes accordingly. The maximum angle of rotation for platform is $\Theta_{max} = 25^{\circ}$ for both sides. In order to have a working angle, the values of adjacent and opposite needed to be determined . Cos and Sin equations cannot be used because the equations does not meet the requirement. 25° angle has been chosen because from the research that has been carried out, the universal ball joint maximum can rotate up to an angle of 30°. The adjacent value which represents the required length of balancing platform used is 4 cm. Therefore in this design, the width of the balancing platform is 4 cm maximum.

The floating structure of UMT refers to the wings that were built from PLA and polystyrene being glued together. The purpose of building the floating structure is to ensure the transporter's floatability when the transporter encounters the pool of water. The wings material used is PLA with two blocks of polystyrene parts attached. This is because polystyrene is lightweight and higher floatability. In UMT, on the side of the polystyrene, there are a part of wings tilted to support the prototype while in the water. The wings was designed to be able to deploy for use whenever activated by user though remote control when the UMT is in the water. This design follows the idea of a pontoon boat. It also implies the use of natural surface tension for example in the case of "water spider gliding" on the surface water. If the transporter were to stay still on the water, it needs an anchoring system to maintain its position.

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As for the floating wings design, the dimension of the both wings are similar with 17 cm in length, 4 cm in width and 6.5 cm tall. The dimensions of the both front and back structure are similar with 3 cm in length, 5cm in width and 4.5 cm height. This design can be fitted onto the transporter.

In designing the floating structure, each part was individually designed and printed before being assembled together. For the wing structures, there are three parts altogether. The first part of the wing structure is made of blocks of polystyrene attached to it. The polystyrene will ensure the UMT is able to float since polystyrene is made out of lightweight material with high floatability. Meanwhile, the middle part which connects the first and third parts is made of steel and it could retract and extend when as needed. Lastly, the third part of the wing structure is attached to side of the body of the transporter. This part of the wing is used to support the first and second parts of the wings to ensure its stability. The movement of the wings is controlled by the servo motor. Activated by user through remote control in the water. The wings are only dispatched manually when they come in contact with the water. When the wings are not used, the servo motor will retrieve the wings.

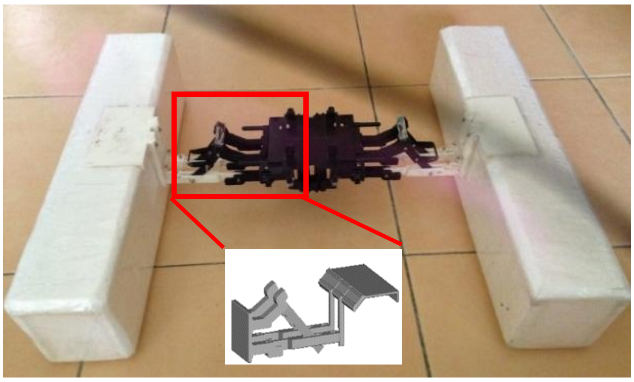

Fig. 3: Overall assembly wings with insets showing retractable middle part design

To ensure the object is able to float on the water, the density of the product should not be more than 1 kg/m3. To calculate the possibility of an object either floats or sinks. This calculation is done based on the assumption that total mass of the transporter is 3 kg. The result of the calculation shows that the density of the product used in this project which is 0.3606 kg/m3 less than density of the water 1 kg/m3. So, the transporter is able to float on the water.

Although a transporter is able to float on the water, without anchoring system, the transporter is unable to maintain in a static position. The anchoring system used in this project follows those of the anchoring systems used in the bigger size real ships or yachts but at a much smaller scale. This anchoring system is mounted at the back of UMT. The servo motor is used to pull-down or pull-up the anchor with nylon fishing line. The line is able to support an object up to 3 kg. The weight of the anchor is 500 g.

Overall prototype assembling of UMT also includes a four-wheeled car (transporter) which is the base/scaffold of this prototype. This transporter needs to be designed to be able to float on the water, move on peak soil area and at all times, stably transport the DFC to final destination. If all the wheels could be independently controlled and actuated. Transporter has a certain degree of flexibility in maneuvering in certain operating cases. Due to the time limitation and cost, this 3D design of transporter was not printed but an existing structure that is available in the market was used. The add-on components for this transporter are the balancing platform, floating wings and anchoring system. This product can move on off-road because it is equipped with suspensions that ensure its rotating ability and movability.

Fig. 4 shows the 3D overall assembly design of UMT. The dimension of the overall assembled design is 40 cm length, 43 cm width and 24 cm height. Balancing platform, floating wings and anchoring system fitted proportionally on the transporter. Platform balancing shall be assembled on top of transporter, wings will be assembly at left and right of the transporter including front and back parts of the transporter to be used as supporting structure. Blocks of polystyrene were used to float on the water surface and anchor was used to keep a static position on water. When UMT moves on ground and on the surface water, the platform will not let the object/DFC fall down.

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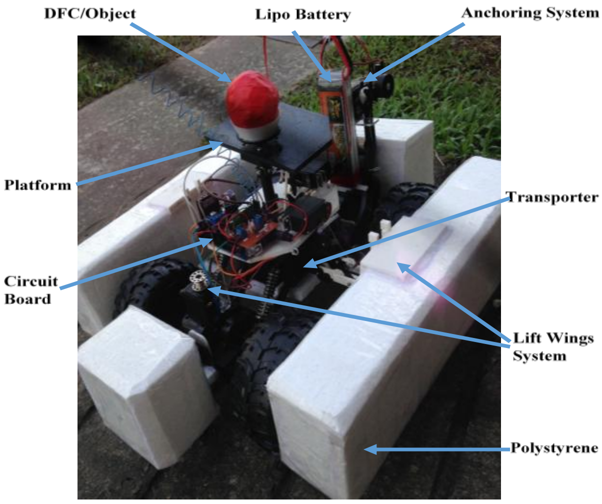

Fig. 4: Prototype of Fully Integrated Unmanned Multipurpose Transporter for Dengue Control in Rough Terrain and Shallow Water Application

IV. RESULT AND DISCUSSION

In this project, there are two groups of interfacing of the UMT required which are at the balancing platform and floating wings together with anchoring system. First group of interfacing refers to the circuit design of how the balancing system is done on the platform. When the input accelerometer sensor detects unbalanced situation, the signal will be sent to microcontroller. Microcontroller will generate the corrective signal to the actuators which are two servo motors. Next, there servo motors will start the balancing process. Second group of interfacing used for the remote controlling system which encounter shallow pool of water, user will initiate and transmit a signal from transmitter (remote control) to the receiver. When receiver received the signal, it will activated the L298N motor driver to lift up or moved down wings by motor. The anchoring system is also using the similar method to release and pull-up by using L298N motor driver. L298N motor driver consists of four terminals. Two of the terminals are used for first motor and while another two are used for the second motor.

433 MHz module is used in UMT prototype. This module is used to transmit and receive data from the encoder and decoder. Integrate Circuit (IC) in this project is using the HT-12E encoder and HT-12D decoder. These encoder and decoder consist of 8-bits address bus and 4-bits data. To improve the transmission range, coiled antenna was utilized. In this project, transmitter and receiver was custom designed and used. Motor loading through DC-DC converter simulation is used to determine the functionality and loading of UMT. For example, simulation was carried out to check the current and voltage reading based on the circuit if install action of six motors. Fig. 5 shows the simulation of the converter of UMT. The purpose of conducting the simulation is to investigate the values of the four capacitors. The higher value of capacitor will store more charges. This could aid in choosing the appropriate converter for the project.

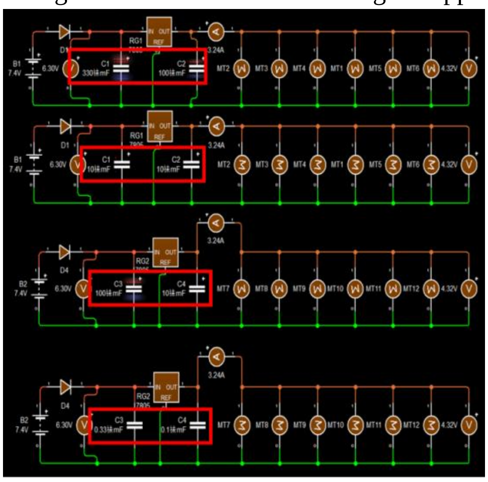

Fig. 5: Simulation of converter as means to verify the functionality of UMT

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Four testing were carried out on the developed prototype under four different testing conditions. The first condition was on a smooth surface with a tilt angle. The task is to test the movement of UMT on maximum tilt angle while keeping its balance on the platform. The second topology that the UMT is tested on is the rocky flat ground. The third topology is on the peak soil condition. The task on the third topology is to test whether a moving object is able to keep its balance or vice versa. The last testing condition is to test the UMT's floatability on the water surface as well as its anchoring system to stay in a static position.
For the first testing condition which is on a smooth platform with an angle, the UMT moved upward carrying the DFC. In this case, the DFC was replaced by a red ball. If the platform is not stable, the red ball will fall down and vice visa. Subsequently, the height of the smooth platform will be increased linearly 4 cm as in Table 1 as to project effectively the increase of tilt angle. The maximum height that the UMT can reach is 48 cm which corresponds to 32.62 tilt angle. If more than that, it will cause the platform to be imbalanced. This can be seen in from Table 1 where UMT has been tested using different heights and angles. From the tests, UMT is able to move stably when carrying a test object at 4 cm height. The test object, which was a red ball, did not fell. This repeated observation was recorded until the height of 48 cm. After 48 cm height testing, the red ball fell down repeatedly at the height between 52 to 56 cm and the respective angle are 34.73 to 36.75°. The maximum angle without load falling off is 32.62°.

Table 1: Results showing of balancing platform according different height of UMT

Length (cm)	Height (cm)	ϴ (Angle)	Red ball falling down from UMT
75	0	0°	NO
75	4	3.05°	NO
75	8	6.09°	NO
75	12	9.09°	NO
75	16	12.04°	NO
75	20	14.93°	NO
75	24	17.74°	NO
75	28	20.47°	NO
75	32	23.10°	NO
75	36	25.64°	NO
75	40	28.07°	NO
75	44	30.40°	NO
75	48	32.62°	NO
75	52	34.73°	YES
75	56	36.75°	YES

Second testing was done on rocky flat ground in an open area. During the testing, UMT was slowly controlled and maneuvered to pass through the rocky flat ground. In this testing, the flat ground has around 60% of rocks in a square area of 1 m x 1 m. The test subject was tested twice on the rocky flat ground. In both of the cases, the UMT was found to be able to move stable when carrying an object without falling off to the ground. The third testing was done on the peak soil with rough surface terrain in an open area. The result shown that UMT successfully balance itself despite moving on rough surface terrain and in the peat-soil. UMT was slowly controlled and maneuvered to pass through the peak soil with rough surface terrain. In this testing, the ground has around 70% of grasses and 30% of water in a square area of 1 m x 1 m. The subject was tested three times on peak soil ground while carrying a red ball. Result shows that the UMT was able to move stably while carrying the object without having it fell for twice. However, the object did fall once. The fall was not due to the instability of the UMT but it was found that it fell when the speed was increased.
The final testing result has demonstrated that UMT can still balance itself when it moved and floated on water surface. UMT from flat ground to the surface of the water while carrying a red ball. UMT was slowly navigated to pass through the water surface. During the testing, the water depth was at 48 cm deep. During two times of testing's, UMT was found to be able to move stably on the surface of the water as well as float well while carrying the red ball. It was also discovered that the UMT was able to anchor in the water in a static position.

This phenomenon is made possible due to surface tension. Surface tension happens when liquid molecules of the water attract to each other and these molecules tends to minimize surface area resulting in an elastic-like surface. Water-borned insects typically use this concept to glide on the surface of the water. UMT prototype used the same concept mentioned above.

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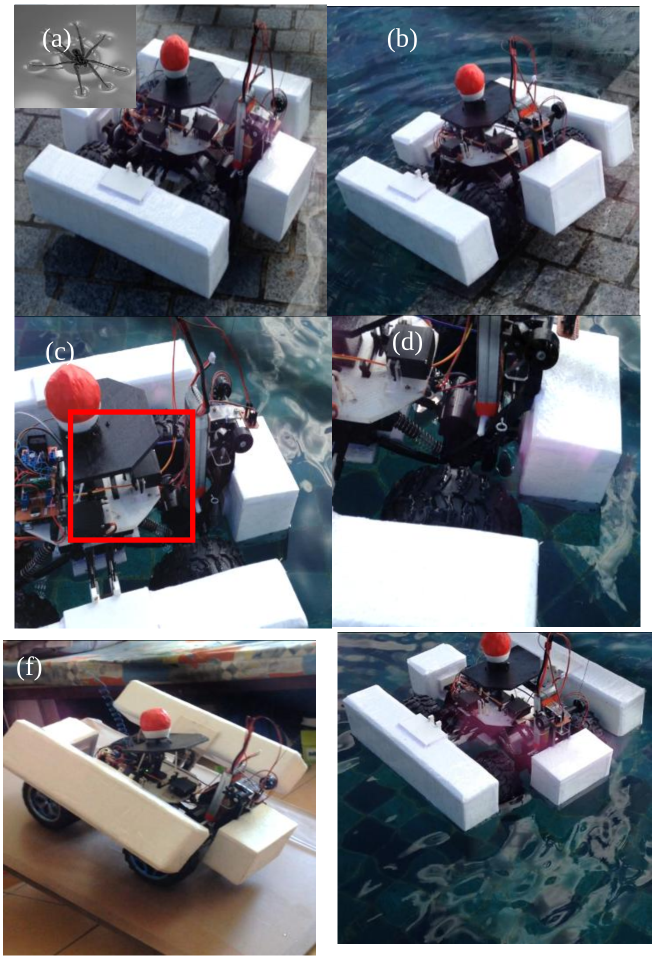

Fig. 6: UMT floats on the water surface mimicking a water spider gliding on the water surface (insets) (a) Ready to move on water surface, (b) Lifts down a pair of wings, (c) Moves on water surface, (d) UMT floats on water surface and releases the anchor into water surface and keeping UMT static at a position and (e) Retracts the anchor and continue moving, (f) UMT moves on a 20 cm height without the red object (ball) falling down.

V. CONCLUSION

As a conclusion, UMT has been tested and validated on different surface areas. The test subject worked well even when it floats. The floating wings, anchoring system and platform balancing worked too.

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