Developing a novel and different micro-robot for marine purpose

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Abstract—We inspired from the motional mechanisms of an inchworm, flexible tuna-tails and batoid fish, by utilizing ICPF actuators, for moving the micro-robot. Since motional mechanism these three animal species to motion the surface and underwater for cleaning of organic pollutants according to a set of superficial processes on the water, used from filtreringsanordning at the moment. Filtration process from micro-robot can be used in water ability purification at surface or underwater in limited places. It also is designed in a way that the filtreringsanordning can be easily installable on the most of micro-robots. The mechanisms and the speed of moving of the micro-robot are calculated theoretically. At last a primary pattern is made (comprises of ten actuators) and a collection of investigations for evaluating the speed of floating and walking motions are done. The six ICPF actuators are utilized to implement grasping motion.

Keywords:
Bio-inspired micro-robots, inchworm- robot, filter, micro ICPF actuator, skimmer F.D.B.O.S.

۱ INTRODUCTION

This paper describes the design of an inchworm robot based on the motion of *Ascotis selenaria*. The ability of movement is the most important property of a micro-robot to accomplish given tasks, and therefore the micro-actuators play an important role in the micro-robotic systems. Most of these robots have been inspired by living organisms (A. Shourangiz Haghighi et al, ۲۰۱٥, Alireza Shourangiz Haghighi et al, ۲۰۱٥, Haghighi, Alireza Shourangiz et al, ۲۰۱٥, Haghighi, AliReza Shourangiz et al, ۲۰۱٥) in nature. In previous works, many micro-robots are developed by using various kinds of smart materials, such as Ionic Polymer Metal Composite (IPMC) (Jung, Sun Yong et al, ۲۰۱٥) Piezoelectric Elements (PZT) (Xiao et al, ۲۰۱۲)pneumatic actuators, and Shape Memory Alloy (SMA) (Moura, T. D. O. et al, ۲۰۱٥) have been investigated for using as artificial muscles in novel types of micro-robot (Rahman et al, ۲۰۱۱, Chettouh et al, ۲۰۰۸). Employing ICPF (Ionic Conducting Polymer Film) actuators as actuators to fabricate a four-finger gripper. Many robotic researchers concentrate on a biomimetic micro-robot in order to mimic natural creatures as it has functional locomotion systems (Zhu et al, ۲۰۱۲). The advantages of soft-bodied robots are reflected in their large and complex deformation, compact architecture, lightweight robot structure, and their control method based on body morphology (Rahman et al, ۲۰۱۳). Among the varieties of creatures, pattern locomotion of an inchworm has appealed the attention of the most researchers around the world (L. Shi et al, ۲۰۱۱). It is well known that an inchworm can move forward by constantly bending and traction its circumferential and longitudinal muscles that is attached to its flexible body also, front/abaft legs grasp the ground with an appropriate timing to make the body moves forward as can be seen in Fig. ۲. In other words, the inchworm motion forward needful changing friction force between front/abaft ends of its body and the ground (J. Koh et al, ۲۰۱۰). Fig. ۳ also clarified the body design and fluid dynamics of species of batoid fishes which are called *Urobatis halleri*. Industry using biomimetic technology (Ren et al, ۲۰۱٤, Wang et al, ۲۰۱۳, Meng et al, ۲۰۱۳, Huang et al, ۲۰۱۲) has achieved significant progress that in the diverse fields of robotics in the covers.

Despite many of biomimetic micro-robot actuated by smart actuators and materials have been developed in recent years, because these characteristics repugnance with each other. ICPF actuators are used to develop a micro-robot with a compact structure, multi-functionality, and flexibility and using micro-robots for monitoring ocean currents, studying animal migration, chemical agents, depth measurements and underwater environments exploration in the future. The actuation characteristics of ICPF, consist a kind of smart film and has the characteristics of elasticity, decent response and being driven by a low voltage .The other trait of the ICPF actuators are that when the frequency of the applied voltage signal is lower than ۰٫۳Hz, the water around the ICPF surface is electrolyzed (Liwei Shi e al, ۲۰۱۰).The inchworm pattern locomotion requires less locomotion space compared to other motion pattern such as wheel or legged walking machines (W. Wang et al, ۲۰۰۹). In this work, inchworm micro-robot in spite of the motion under the surface of the water by changing the volume continuous function of ICPF actuators and by electrolyzing of the water to do floating motions to the surface of water in order to poll from the organic structures of the surface of the water by utilizing the skimmer and the motional mechanism of the biomimetic of the batoid fish. We inspired from the mechanism of inchworm batoid fish and butterfly for improving and speeding the motion of the micro-robot. In this research a new type inchworm-batoid fish inspired micro-robot is developed with ten ICPF actuators utilized as legs or fingers. This unit employed four of its actuators to walk, float, and rotate motions. The other six actuators were used to implement grasping. And the rest of paper is organized as follows:

Section ۲ establishes the multi-functional locomotion based on ۱-DOF and ۲-DOF. A novel type of underwater micro-robot, using ICPF actuators as legs or fingers which can do floating, walking, rotating, and grasping motions were clearly introduced. Section ۳ states the skimmer is designed, since the organic samples are made in limited places. D.B.O.S system uses the difference of the density of the water and the organic sample make it possible to collocate the sample from the organic species and transfer samples to the laboratory anytime. At the moment, this micro-robot is the first vehicle with small structures scale beside, filtration process from the surface of the water in impenetrable and generally non-traffic environments. It should be noted that it has the aptitude of moving underwater, then again, it cleans the water of the different places, and also some advantages are presented. And the last our conclusion.

Table۱. The list of abbreviations:

IPMC	*Ionic Polymer Metal Composite*
ICPF	*Ionic Conducting Polymer Film*
SMA	*Shape Memory Alloy*
DC	*Direct Current*
DOF	*Degrees Of Freedom*
SSC	*Smart Soft Composite*
FDBOS	*Filtration Density Base Organic Structure*

۲ PROPOSED MULTI-FUNCTIONAL UNDERWATER

۲.۱. Proposed underwater Micro-robot structure

A novel and applicable biomimetic structure with ten ICPF actuators is considered in this work. With respect to combined inchworm- batoid fish, and the structure of skimmer, our design will be limited. For instance, the proposed skimmer only water purifiers on the surface of water, so lying mode is selected. Inchworm also can do only walking motion. Hence, two kinds of motion is compulsory. Hence, the first one is standing mode, and the second one lying mode.

In order to understand the two motions of the following figure along with the order of ICPF actuators are introduced in Fig. ۱ is introduced. It is simple yet more efficient mainly in restricted places and obstacle avoidance. Since the micro-robot should be multifunctional locomotion, the proposed actuators play a significant role in this research. With these actuators (legs or fingers) robot can move in longitudinal and transverse directions, do grasping and floating motions, lying and standing structures, swimming, walking in the air, and also walking in a flat surface. These locomotion demonstrate the proposed robot is multifunctional. As illustrated in Figs. ۱and ۹, legs I through IV rather than other actuators have ۹۰° phase difference. The reason for the ۹۰° phase difference can be for longitudinal and transverse directions based on its locomotion. More detailed information is clarified in the relevant section. As can be inferred that actuators I through IV are used as the legs which have a significant role in its locomotion. Note that they can be used as the following legs or the leading legs.

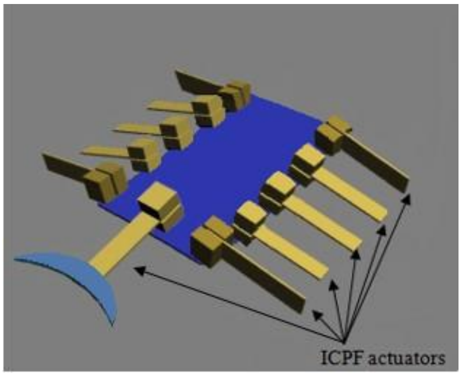


Fig. ١. Proposed biomimetic structure (lying structure)

٢. ٢. Discipline and driving mechanism of A. selenaria and U. halleri

This paper analysis and delineations of the design based on the movement of *A. selenaria* and *U. halleri*. To mimic the locomotion patterns of the inchworm's behavior in nature, and observed carefully what motions could be made by *A. Selenaria* and chose motions as can be seen in Fig. ٢. *A. Selenaria* is a species of an inchworm with a locomotion pattern similar an omega bending motion in between the extension motions (Koh et al, ٢٠١٠). This species of inchworm can journey roughly its body length per move on a ragged surfaces, climb of leaf edges and branches of trees.

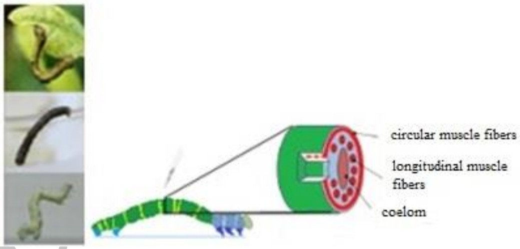


Fig.٢. a cross section of its abdomen showing its main muscle structure and locomotion patterns of inchworm.

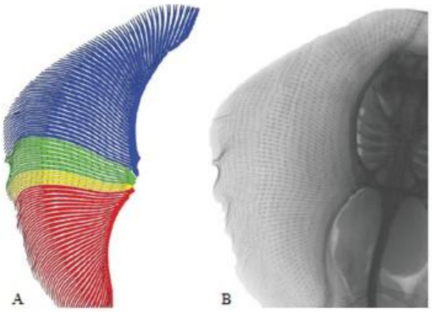


Fig.٣. Schematic overview joint position of the wing skeleton and flexibility distribution of *U. halleri*.

A: Overview of individual skeletal elements from radiograph. Dissimilar colors signify origins of radials from different skeletal elements of the pterygial complex.
B: Radiograph of the left side of *U. halleri*. Dark indicates radio-opacity. Anterior is at top of page.

۲.۳. Mechanism of the walking motion

In former investigations, the walking mechanism of inchworm with one and two DOFs are considered. It is obvious that the micro ICPF actuators make the micro-robot move to the four directions in this research. As can be seen clearly, these actuators are in sequence parallel to the length. We would face problem in order to walk in both East and West directions. Fig.٤ clarified that four legs have different phase. Consequently, devoid of adding another four actuators, this problem was creatively cracked. In order to understand the walking mechanism, the following and leading legs were introduced. It is worth noting that the micro-robot can simply move to the four directions. In this section two directions would be described. Henceforth, Based on the situation one leg was known as the leading leg, and the other as the following leg. If the micro-robot is walking in East or West direction, the leading and following legs will be the same as in Fig.٤, otherwise the leading and following legs would change to get to the longitudinal direction.

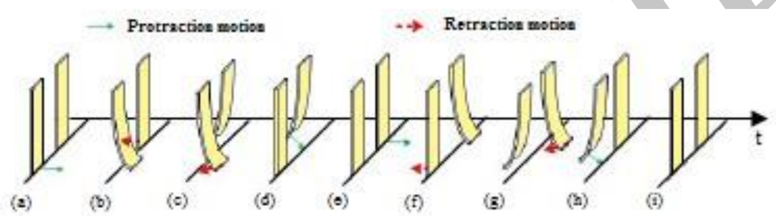


Fig.٤. Locomotion of walking micro-robot. The green thin arrows show the protraction motions, preparing for next step. The red thick arrows show retraction motions which touch the ground and robot keep moving forward.

In order to simulate the speed of gait motion of the proposed robot, the displacement of the actuators and the input frequency were considered. Note that the displacement of the ICPF actuator in an actual application is demonstrated by *d* the actuator, an also the displacement of the ICPF actuator without payload is demonstrated by $d.$. Regarding the viscosity, water resistance, vortex shedding damping, potential damping, payload, and other factors, the displacement of the ICPF drivers diminish by a non-negligible amount ١*d*. Hence, the relationship between *d*. and *d* and the gait speed of the micro-robot can be expressed as (Bruno Siciliano et al, ۲۰۰۸):

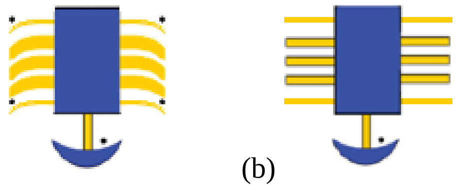
$$d = d. - \Delta d \qquad (١)$$

$$v = ٢\ (d. - \Delta d) f \qquad (٢)$$

۲.۳.۱ Analysis of the Micro-robot Motion

The processes of floating up and down are the same. The step cycle of floating up motion can be separated into two periods (a) and (b) as shown in Figs ٥, ٦.

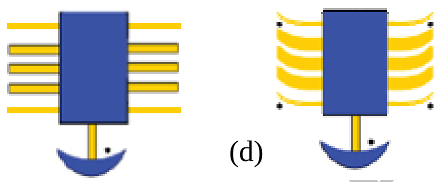
One step cycle of floating up is shown in Fig.٥. Both ends of the ICPF switch on the current, the ICPF toward the cathode bending. When the six legs of the proposed robot are connected on the similar square signal, then all ICPF actuators will bend in the desire direction. Finally the robot can make the robot float upward.



(a) (b)

(a) The micro-robot without input voltage. (b) The robot with input voltage.
Fig.٥. Schematic diagram of the micro-robot to rise.

One step cycle of the floating down is shown in Fig ٤. From (c) to (d), the drivers push the body to floating down.



(c) (d)

(c) The micro-robot without input voltage. (d) The micro-robot with reverse input voltage.
Fig.٦. Schematic diagram of the micro-robot to float down.

۲.۳.۲ Walking simulation in air

Legs V through to X were used to move in transverse direction and legs I through IV were used in order to move in longitudinal direction (see Fig.٧). Now, if transverse direction was selected, legs II, III were used as leading legs and legs I,III were used as following legs ,while in longitudinal direction legs order would change.

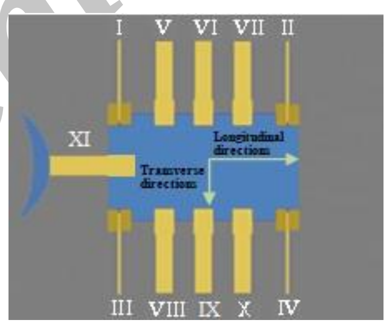


Fig.٧. Top view Sequence of ten legs of the micro-robot. (In lying mode)

Based on longitudinal and transverse directions, it can be clarified that ICPF actuators I through IV have a significant role in the proposed robot in this work. In order to simulate the walking speed one of longitudinal or transverse directions must be chose to have the highest efficiency. Therefore, two directions were simulated, and the graph of the two simulations were ١٠٠٪ fit (by using command Correlation MATLAB ٢٠١٥a). This simulation result clarified that two direction could be chosen and the efficiency of them will be equal. It is worth noting that the whole frequency of legs must be the same. If the frequencies are not equal, the micro-robot won't mimic bio-inspired motion or maybe lose its equilibrium. As can be seen in Fig.٨, ten frequencies are chosen to appraise its performance in different positions.

It can be seen the simulation results in Fig.۸. It can be inferred as follows:

۱. At ۷V, maximum of walking speed ۰,۹۰ mm/s was achieve at ۰,۷٥ Hz.

۲. At ٤V, maximum of walking speed ۰,٥۰ mm/s was achieved at ۰,۷٥ Hz.

۳. Before ۰,۷٥ Hz walking speed in air increased quickly, and after ۰,۷٥ Hz walking speed in air reduced so that the value become zero within ۲,۸۳ to ٥ Hz.

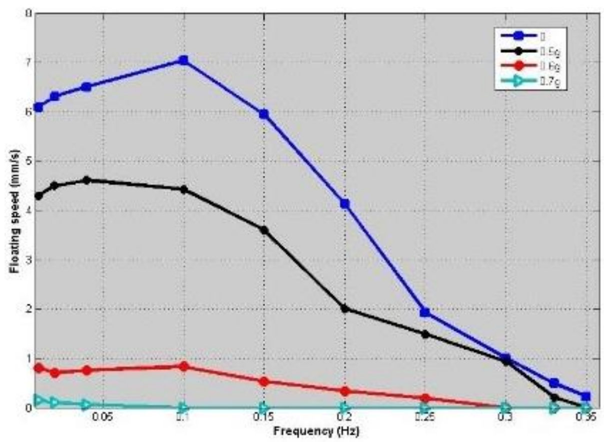


Fig.۸. Theoretical floating speed results with and without payloads (۷V).

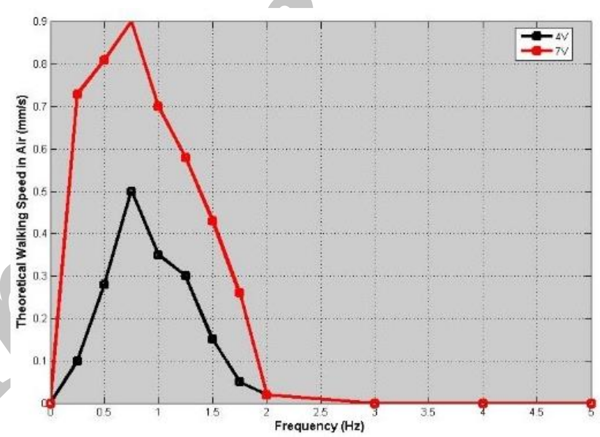


Fig.۹. Theoretical walking speed results in air.

۲.۳.۳ Grasping and floating simulations with and without payloads

The key purpose of emerging biomimetic underwater micro-robots is to enable monitoring operations, for instance video mapping in narrow and restricted places or in amorphous underwater environments, and also note that it itself must carry the object. The two most valuable characterizations of grasp restraint are *form closure* and *force closure* .These terms were in use roughly ۱۲٥ years ago in order to differentiate between joints which required an external force in order to maintain contact, and those that did not (F. Reuleaux, ۱۹٦۳). Since the aim of this research is to grasp tiny simple object therefore we don't get into the details. Carrying objects can be a camera, which is installed on a structure, or skimmer, which is cited in this paper, in this research. Hence, the study of grasping is too important.

Therefore, in order to get the purpose of this work first grasping, and then floating with payloads are considered. The biomimetic of combined inchworm and batoid fish in just a different micro-robot was presented without any flaw, although it is a hard job. It can be seen obviously in Fig.۹ the simulation results of floating speeds with and without payloads (MATLAB ۲۰۱۵a).

From the simulation results, it can be inferred that:

۱- The Tuna-robot can easily carry ۰,۵g, and the maximum floating speed ٤.۱۳mm/s was achieved.

۲- The robot can carry up to ۰,۶g, and floating speed diminishes to precisely ۰,۹۳mm/s, as can be seen in Fig. ۱۰.

۳- When the biomimetic micro-robot is without payload, as can be estimated, the Tuna-robot will have the maximum floating speed ۶,۵ mm/s. This section along the previous section clarifies the multi-functional locomotion of the robot based on inchworm-batoid fish inspiration.

۲.٤. Mechanism of the rotating motion

As can be seen, in Fig.۷, the two legs I and IV are used as following legs and legs II, and III are used as leading legs, this simple movement make the micro-robot simply rotate clockwise.

If the leading and the following legs were changed, the counter-clockwise rotation is the result of the micro-robot. The speed of the rotating motion can be only calculated by the frequency of the pace and rotational angle covered in a single cycle (Richardson et al, ۲۰۰۹, Janna C Nawroth et al, ۲۰۱۲).

The displacement of a single ICPF actuator by implementing different signals was carefully calculated in order to simulate the theoretical crawling or walking speed of the robot. The theoretical displacements d_0, without payload, of the actuator can be seen in Fig.۱۰.

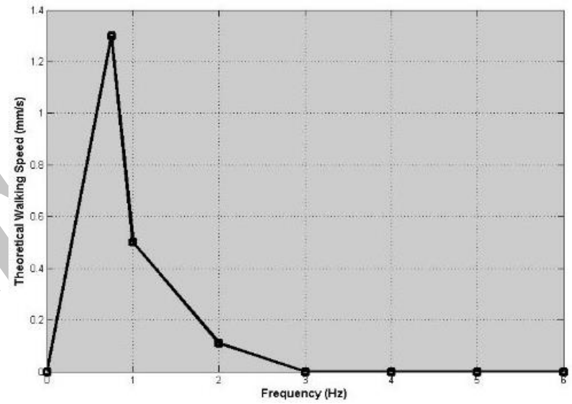


Fig. ۱۰. Theoretical walking speed of the micro-robot (۷V).

Fig.۱۱ demonstrated the simulation outcomes of the theoretical walking speed discreetly. It can be determined that if the frequency increases, the dispalcements of all micro actuators escalate. Accordingly, it is a good sign for the reason that the proposed micro-robot have a maxiumam walking speed. Developing a faster is vital in the field of micro-robots in the future. since fast response is significant in micro-robots, and also in nano-robots.

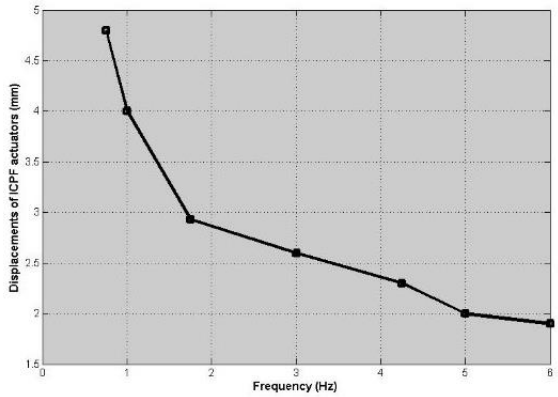


Fig.١١. Displacement (d٠) of the ICPF actuator (٧ V).

٢.٥. Mechanism of the floating motion

As can be obviously seen in table ٢, buoyancy force evaluated and compared with quantity mg. Buoyancy force is an upward force applied by a fluid that opposes the weight of an immersed object. Thus a column of fluid, or an object submerged in the fluid, experiences greater pressure at the bottom of the column than at the top. This difference in pressure results in a net force which inclines in order to accelerate an object upwards. The magnitude of that force is proportional to the difference in the pressure between the top and the bottom of the column, and is also equivalent to the weight of the fluid that would otherwise occupy the column, i.e. the displaced fluid.

For this reason, an object whose density is higher than that of the fluid by which it is submerged tends in order to sink. If the object is either less dense than the liquid or is shaped correctly, the force can keep the object floating. This can just happen in a reference frame which either has a gravitational field or is accelerating because of a force other than gravity defining a "downward" direction (that is, a non-inertial reference frame) (Liwei Shi et al, ٢٠١١). The center of buoyancy of an object is the centroid of the displaced volume of fluid. It is worth noting that buoyancy force is independent of shape. The buoyancy force is defined as:

$$F_b = \rho g(v + \Delta v) \qquad (٣)$$

where ρ is the density of the water, g is the velocity due to gravity and supposed to be ٩,٨٠٦ , V is the volume or size of the micro-robot, ΔV is the volume or size of the bubbles. Remember that the volume of the bubbles frequently supposed to be zero. It can be concluded that floating motion is one of the most important section in this research.

Although motions such as, floating, walking, standing, lying are simple but too important because the combination of these simple movements could be, like sections ٢.٣.٢ and ٢.٣.٣, used in different situations to achieve our purpose.

Table ٢.Buoyancy force in robot (Shuxiang Guo et al, ٢٠١٢).

$F_b > mg$	floating upward
$F_b = mg$	suspended
$F_b < mg$	Sinking downward

Buoyancy force was functioned in MATLAB since it is an important force which will be used in future.

۲.٦. Simple Algorithm for obstacle avoidance

In fact proposing an underwater micro-robot without considering obstacles will be so useless. Now, bio-inspired inchworm-batoid fish with embedded skimmer system is proposed to do mechanisms such as floating, walking, rotating, and moreover lying mode. These mechanisms will help the micro-robot to bypass the obstacles. So ultrasonic sensor (AVR-ATMEGA ۳۲) are chosen.

Ultrasonic sensors that are mounted on the micro- robot body, detect the distance robot and the objects which are close to it. The processor measure the time interval between the sent signals from the reflected back according to the robot speed and distance to the obstacle, the robot bypass and take the safe route. (See Appendix II (P. Fiorini and Z. Shiller, ۱۹۹۸, R. Simmons, ۲۰۰٦, J. Minguez and L. Montano, ۲۰۰٤)).

۳. FILTRATION DENSITY BASE ORGANIC

۳.۱ The structure of skimmer (F.D.B.O.S)

Organic and chemical substances are created in limited places. Skimmers, mechanical devices that are designed to collect pollution from surface and inside the water due to their size these devices are of high efficiency. Skimmers consist of independent parts that can to be installed on micro-robot. Performance skimmers in variety cases such as the thickness of the oil layer, the weathering, the emulsion of oil, the solid particles in water, weather conditions and time to collect an organic and chemicals from the water. In order to F.D.B.O.S system is designed for filtration of chemical and organic materials on the surface, the sea floor and float mode is used in the aquatic and the deep sea environment and Inaccessible Fig.۱۲ clarifies structure of the F.D.B.O.S system in detail.

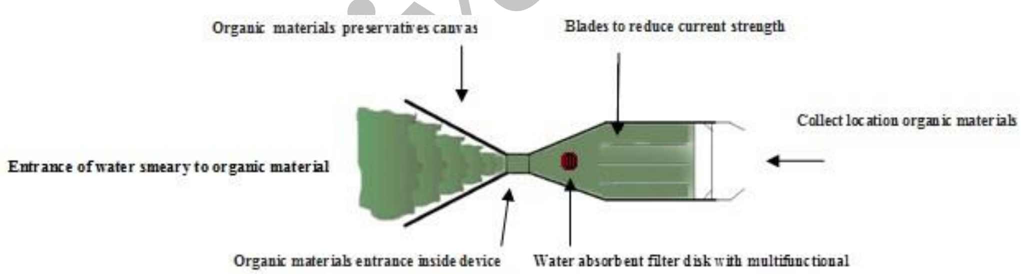


Fig.۱۲. Top view of the separation of oil and water based density Skimmer F.D.B.O.S.

Performance F.D.B.O.S system filtration and collected to the volume organic and chemicals from the water depends on the volume measured by time units, for example cubic meters per hour and a range of expression. If these values are usually based on the amount of water inside the F.D.B.O.S system, then the amount of water in the oil will affect the collection. In addition to the above mentioned characteristics related to yield one of the most important characteristics of skimmers, their ability to create an emulsion. Also their ability to deal with particles, ease of preparation, strength, usability and reliability of this equipment in certain areas than others is. The section the filtration and separation of organic materials and water that form a non-regular hexagonal designed. Implementation of the filtration and separation process is based on the density difference between organic materials water. When the water is contaminated with toxic organic and driven into the device at the time of spinning through the filter after the filtration process and from the diagonally page contains numerous pores passes.

This page has been connected with a number of vertical frames and in addition to being impregnated with toxic substances from water turbulence stops, then slowly move forward in the creation of the four separate channels, and to lead well. (See Fig.۱۳) The channels in order to avoid creating eddy current and rotational in the water has been built. Slow-moving water impregnated with toxic substances in the course of these channels provides the possibility of depositing toxic material max. After separation of the water that is in the lower part of the adjustable vents embedded in the floor exits and toxins are deposited into the tank terminal guidance.

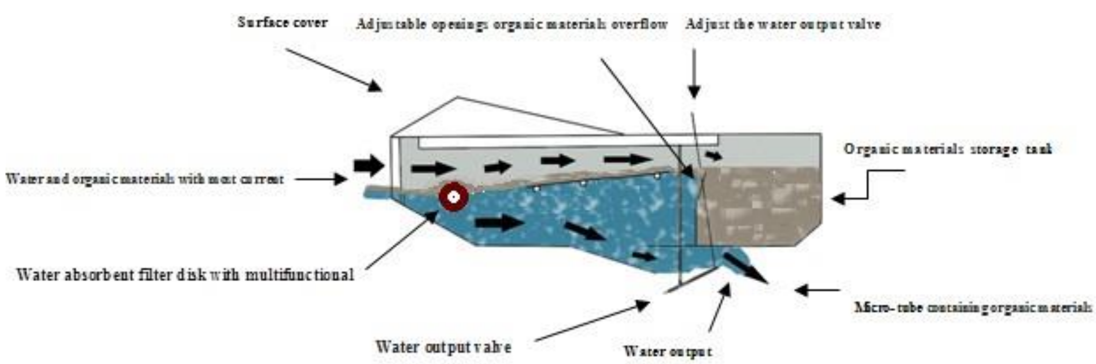


Fig.۱۳. Filtration Density Base Organic materials Skimmer F.D.B.O.S

۳.۲ Electro-Magnetic valve

In this section, our aim is to open/close the cap of the proposed skimmer in every moment. Contactor consists of an electric magnet which has a rotational section, and a fix part of separate or connected by a single spring. Note that the contactor connected to the rotational part of a series of contacts are insulated with that rotate. When the magnetic coil passes through a certain flow moving contacts by the magnetic force of the fixed contacts are pressed at the same time one or more springs are compressed or stretched. However when the voltage is interrupted or under a certain limit. Spring forces causes the contacts automatically separated. The prototype of an electro-magnetic valve is shown in Fig.۱٤.

Fig.۱٤.The prototype of an electro-Magnetic valve

۳.۳ filter characteristic and structure

Micron filter polypropylene is one of the most important equipment water treatment. To remove toxic and harmful substances and other sediments to the micron grain size polypropylene, micro filtration process can be used in water purification. Due to the high density fiber particles remain on the outer surface of the water with particles less than five microns which entered to the system. Figs.۱۵ and ۱۶ show the prototype and components of the absorbent filter in detail.

Fig.۱۵. Prototype of an absorbent filter

Fig.۱۶. Components of an absorbent filter

Due to the amazing performance of the system and removing impurities from water and wastewater treatment sewage, in many cases, this system is used in this research. Among the environmental applications of this system include:

۱- The removal and cleaning of organic pollutants from drinking water.
۲- Waste water treatment plants for example nuclear power plants in order to reuse them in the future.
۳- To clean up oil-contaminated water.
٤- To clean up of the groundwater resources of the organic pollutants.
۵- Urban and industrial wastewater treatment and sanitation such as sullage containing heavy metals and toxic substances separation and resumption of valuable materials such as tremendous metals from the sewage of some special units.

٤ Conclusions and future works

Due to the water crisis, people are always looking for solutions to use the water resources of the oceans and seas by using diverse technologies. Using of filtration technology is one of the most important and also the best technique in order to use the water sources for humans and also animals. In this paper a new model of the micro-robot with floating collector skimmer, which is included inchworm and batoid fish and flexible Tuna-tail with small structures, along multi-functional locomotion and flexible structures by using ten ICPF actuators is introduced in detail. Using the method of purification through the micro-robots has the advantages as follows:

۱. The use of mechanisms several Aquatic Animals in the motion micro-robot (better performance for micro-robots).

۲. It is multifunctional locomotion especially in limited and dangerous places. Four actuators (legs I, II, III. IV) of the inchworm micro-robot is used as the foot for swirling , walking , and floating motions and other actuators are used for implement motion.

We calculated and analyzed the function of the embedded skimmer to the foot and the walking speed theoretically. In spite of the ability in biomimetic the batoid fish motions, has the ability of doing the floating motions in the order of the filtration of the organic structures of the surface of the water. A unique feature of the proposed paper if compared with its past papers can be used skimmer (for the first time) in order to increase the speed and improve the design by using the difference of the density of the water and the harmful substances (organic pollutants, sullage containing heavy metals and toxic substances) in any moment make it possible to collocate, isolated and cathartic the compounds from environment anytime The reservoir is designed in order to preserve the proposed harmful substances, and this makes the possibility of quick and easy transfer of the compounds to the resumption and conservation compounds and lead to the safe place. Though it is not possible to build a device without weakness, therefore the proposed micro-robot has few weakness which must be investigated in the future as follows:

١. Using the materials which can effectively mimics batoid fish movement except IPMC and ICPF.

٢. As can be seen obviously in Figs.١ and ٧, the developed robot cannot grasp spherical objects.

٣. The micro-robot which is inspired from fish cannot move backwards (in cruise motion).

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