Experimental Analysis of Plasmodium's Computation Properties for Biological Amorphous Robotics

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ABSTRACT
The Plasmodium of Physarym polycephalum has been studied in the biological and engineering community as a potential biological substrate which is capable of exhibiting properties concerning parallel and concurrent computation .several experiments have shown its capability to optimize graphs and combinatorial geometry. In this paper, we propose the utility of this plasmodium computing, in minimum resistance surface like water, basic tree structures and manipulation of light objects. We further speculate that the results of these experiments can help create biological amorphous robots.

General Terms
Artificial Intelligence, Experimental Study.

Keywords
Amorphous Robotics, Biological computing, Physarym Polycephalum

1. INTRODUCTION
Physarym polycephalum is a slime mould which is visible to naked eye. The plasmodium of the slime mould is a single cell substrate which is formed when thousands of individual cells of Physarym polycephalum fuse together while swarming. It is found out that the plasmodium forms veins of protoplasm. The veins can branch, and eventually the plasmodium spans the sources of nutrients with a dynamic proximity graph, resembling, but not perfectly matching graphs from the family of k-skeletons [3].
The size of the plasmodium is large, allowing the single cell to be amorphous. The plasmodium displays synchronous oscillations of its cytoplasm throughout its cell body, which can be seen as a spatially extended nonlinear excitable media [4, 5]. These oscillatory patterns control the behaviors of the cell. The parts of the cell act simultaneously in a co-operative manner in exploring the space, searching for nutrients and optimizing network of streaming protoplasm. Due to its unique features and relative ease of experimentation with, the plasmodium became a test biological substrate for implementation of various computational tasks. The problems solved by the plasmodium include maze-solving [6,7], calculation of efficient networks [9,10,12], construction of logical gates [17], formation of Voronoi diagram [12], and robot control [18]it is also used as a biological example to study and improvise swarm robotics. Encapsulating it in an elastic membrane allows the plasmodium to not only compute the spatially distributed data-sets but also to physically manipulate the various elements of the data-sets. If a controllable and, ideally, programmable movement of the plasmodium and manipulation by the plasmodium could be achieved, this would open ways for experimental implementations of amorphous robotic devices. There are already seeds of an emerging theory of artificial amoeboid robots [19, 20, 11].

In this paper, we present the results of various experiments conducted, which establish the groundwork of Physarum robotics, using water as the physical substrate for physical development. We show that the plasmodium finds the shortest path towards the food elements by dynamically modifying its physical topography and also how it manipulated about small objects floating on the water surface with the help of its pseudopodia.

2. PROCEDURE OF EXPERIMENT
Physarym polycephalum was cultivated on wet tissue papers in dark but airy containers. Oat flakes were the substrate used for the bacteria on which the plasmodium feeds itself. Petri dishes, having base diameters 20mm and 90 mm, and rectangular plastic containers, having dimensions 200mm by 150mm were used to conduct the various experiments for observing the behavior of the plasmodium and to conduct the various experiments to establish the desired proposition . The dishes and containers were filled with distilled water which acts as the physical substrate for development of the plasmodium. We have chosen water surface as an experimental substrate because there is minimal friction and cohesions between the plasmodium's pseudopodia and the surface, always near ideal humidity for the plasmodium, continuous removal of metabolites and excretions from the plasmodium's body and protoplasmic tubes, increases chances of achieving manipulation of objects by the plasmodium. Data points are represented by 5-8mm pieces of plastic foam which are fixed to the bottom of the containers and oat flakes are placed on top of these foam pieces. Tiny pieces of foam are left free floating in the test arena to observe the ability to manipulate elements physically. The plasmodium is initially placed on a foam piece and anchored to the bottom of the container.

3. RESULTS

In order to prove that the plasmodium can be used for robotic implementations, we need to show that it is capable of sensing the surroundings and reacting to the various changes in a controlled and predictable manner. It must respond to external stimulus and further show that it can solve complex computational tasks on spatially distributed data sets, locomotion, and manipulation of objects. We show basic demonstration experiments which display the ability and potential of the plasmodium to be used in future experiments on laboratory implementation of biological amorphous robots.

The surface tension of water provides sufficient support for the propagation of the plasmodium as its weight to contact ration is very less. The plasmodium gives rise to pseudopodia, whose aim is to search for sources of nutrients. Growth part of the pseudopodia has tree-like structure for fine detection of chemo-gradients in the medium, which also minimized weight to area ratio. Examples of tree-like propagating pseudopodia are shown in Fig. 1.

Figure 1. The tree-like propagating pseudopodia of the plasmodium.

We can observe that the pseudopodium does not always grow towards the source of nutrients. It grows in the south-west direction when no source of nutrient is detected as seen in fig. 2. This usually happens in occasions where the volume of air is large and hence it does not support a reliable and sufficient gradient for chemo-attractants. This poses a difficulty to locate and span all sources of nutrients in large-sized containers having huge volumes of air. Hence we should conduct the experiments in a controlled surrounding where the air is considerably stationary and the test container is not very large.

Figure 2. Growth of pseudopodia in south-west direction in absence of nutrients

In the mentioned controlled test environment, the plasmodium easily locates the source of nutrients. It builds spanning trees where graph nodes, which are to be spanned, are presented by pieces of foam with oat flakes on top. In fig. 3 we can observe that the plasmodium, which was originally positioned in the southern domain, builds a link with the western domain within 12 hours and then proceeds for the eastern domain. When the plasmodium spans, it produces many redundant branches, which are necessary for space exploration

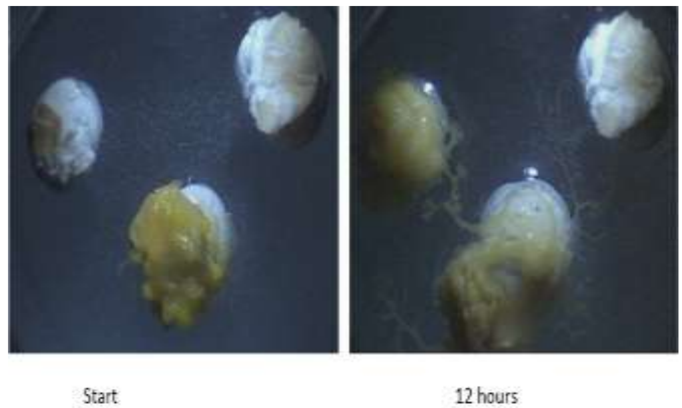

Figure 3. Building of the spanning tree where graph nodes are represented by foam pieces.

But they do not represent the minimal edges connecting the nodes of the spanning tree. These branches are later removed as the spanning tree develops. We can observe a well establish spanning tree in fig. 4, where initially the plasmodium was placed in the western domain and in 15 hours a spanning tree was constructed.

After demonstrating the ability of the plasmodium to explore space and to compute a spanning tree on water surface when place on a floating object, we put the plasmodium on bare surface of water. We observe, as seen in fig. 5, that plasmodium reaches the stationary domain with oats in 8 hours. In usual conditions (on a wet solid or gel substrate) edges of spanning trees, presented by protoplasmic tubes, adhere to the surface of the substrate [9]. Therefore the edges cannot move, and the only way the plasmodium can do a dynamical update is to make a protoplasmic tube inoperative and to form a new edge instead (membrane shell of the ceased link will remain on the substrate.

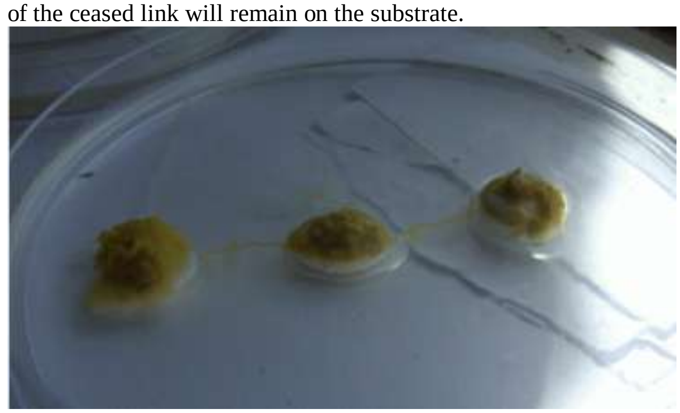

Figure 4. Spanning tree of three points developed by the plasmodium.

When plasmodium operates on water surface, cohesion between the water surface and membrane of protoplasmic tubes is small enough for the protoplasmic tubes to move freely.

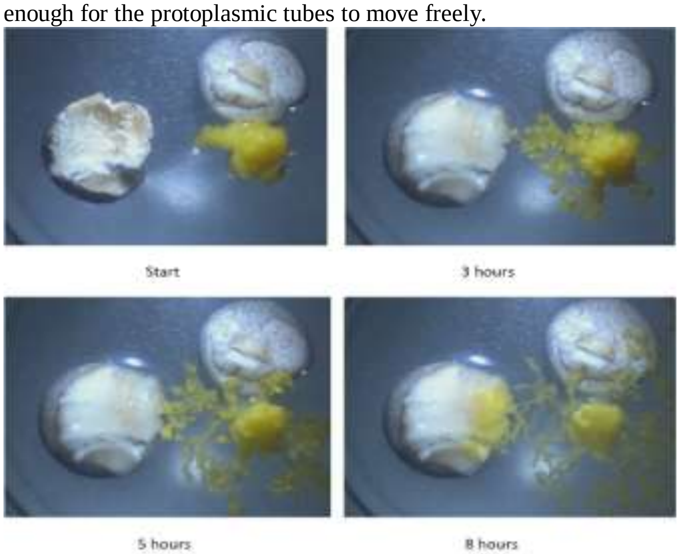

Figure 5. Development of plasmodium on bare water surface.

Thus the plasmodium can make the tubes almost straight and thus minimize costs of the transfer and communication between its distant parts. The examples of such straightening can be seen in fig.6. Straightening of protoplasmic tubes is due to the tubes becoming shorter as the result of contraction. Contraction may suggest that if two floating objects are connected by a protoplasmic tube then the objects will be pulled together due to shortening of the protoplasmic tube. We were unable to demonstrate this exact phenomenon of pulling two floating objects together, however we got experimental evidence of pushing and pulling of single floating objects by the plasmodium's pseudopodia.

In order to demonstrate pushing, a light and small piece of foam was placed near the plasmodium. A pseudopodium is developed which propagates towards the piece of foam. After 9 hours, it is seen that the piece of foam is pushed away from the growing pseudopodia tip. This occurs due to the ripple formed on the water surface by the gravitational force acting on a pseudopodium. After 16 hours, the pseudopodia are retracted by the plasmodium when it discovers the absence of nutrients on the pushed foam. The piece remains stationary but it is shifted from its original position. This entire process can be seen in fig. 7.

For the observation of the pulling phenomenon of the plasmodium, a piece of foam is place between two anchored objects. One object hosts the plasmodium while the second object has an oat flake on top. A pseudopodium grows from the plasmodium's original location towards the site with the source of nutrients. The pseudopodium occupies the piece of foam after a period of 15 hours and then continues its propagation towards the source of nutrients. When the source of nutrients is reached after 22 hours the protoplasmic tubes connecting two anchored objects contract and straightens thus causing the light-weight object to be pulled towards the source of nutrients which can be observed in fig. 8 after duration of 32 hours. The pushing and pulling capabilities of the plasmodium can be utilized in constructions of water-surface based distributed manipulators.

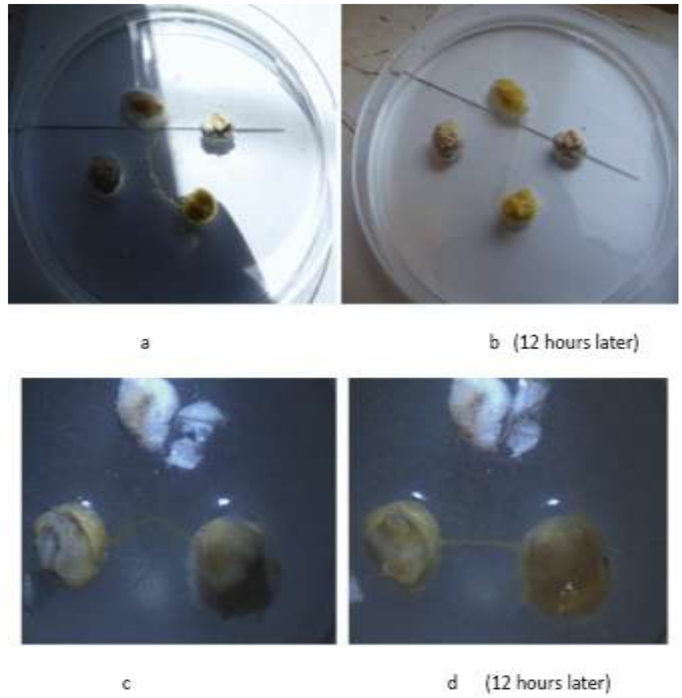

Figure 6. The straightening of the protoplasmic tubes giving rise to minimal shortest path connecting the two sites.

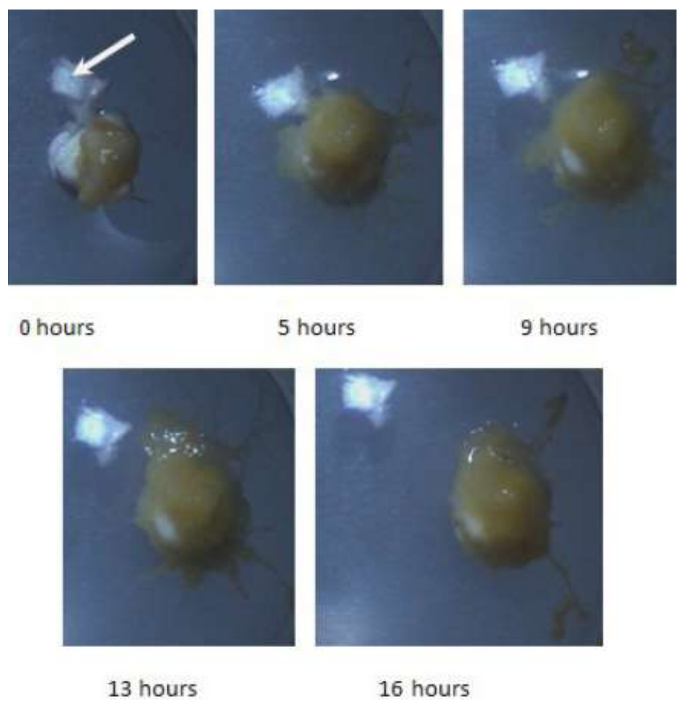

Figure 7. The series of photographs demonstrating the node pushing ability of the plasmodium. The small piece shown by an arrow in the first photograph is pushed away by the pseudopodium.

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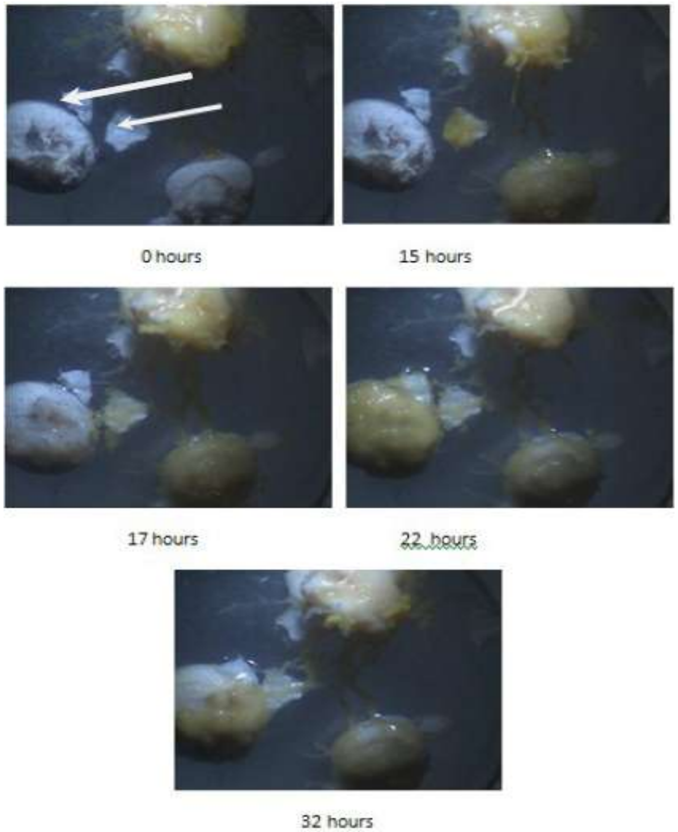

Figure 8. The series of photographs demonstrate the ability of the plasmodium to pull light weighted objects. The foam piece pulled in indicated by the white arrow.

4. INFERENCES

Inspired by the biomechanics of surface walking insects, ideas to design and fabricate biological amorphous robots are studied. In this paper, we aim to show the potential of the plasmodium of Physarym polycephalum for distributed robotics devices and show some necessary features like sensing, manipulation, locomotion and computing. We were successful in experimentally demonstrating that plasmodium can sense data objects represented by the pieces of foam. It calculates the shortest path between the data objects and is capable of conjuring an approximate spanning tree where the data objects are nodes. We can say that, in principle, a spanning tree of slowly moving data objects can be calculated. It can push and pull light-weight objects which are placed on water surface. This proves it to be a potential candidate for the role of spatially extended robots implemented on biological substrates.

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