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RESEARCH ON THE DESIGN FOR PROTECTING THE ARDUINO-MEGA MICROCONTROLLER USED AT AQUATIC EXPLORATION

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Abstract: *National Geographic reports that approximately 80% of the ocean floor remains uncharted, while nearly 90% of marine species remain undiscovered. Scientists continually seek more efficient methods to enhance accessibility and safety in ocean exploration. Over time, they have increasingly integrated the Arduino Mega microcontroller into their projects due to its affordability, versatility, and capacity for large-scale applications.*

This paper focuses on designing a waterproof casing for the Arduino Mega microcontroller, intended for extreme use in deep-sea exploration. The casing undergoes sequential static simulations at various depths, followed by thermal simulations to assess the heat sink's efficacy. The casing aims to protect the microcontroller and its components from physical shocks, allowing uninterrupted utilization of its functions without the need for case to be opened. By guarding against irreversible damage from water, dust, and impact, this protective enclosure stands to reduce research expenses associated with new exploratory technologies and methodologies.

Moreover, this research offers practical utility to a broad audience, spanning from enthusiasts and amateurs to academics, enabling them to construct systems for further ocean floor exploration. Additionally, it serves as a launch pad for novel advancements and refinements in the field.

Key words: *CAD, FEA, Arduino Mega, Deep-Sea, exploration, waterproof, shockproof, protective case.*

1. INTRODUCTION

According to National Geographic, up to 80% of the ocean floor is still unexplored, and up to 90% of the species living in the ocean are still undiscovered [1].

To push these boundaries, scientists are constantly looking for more effective ways to make ocean exploration more accessible and safer. To make this possible, they started integrating the Arduino Mega microcontroller board in their projects due to its capability to perform a wide range of tasks. Additionally, it has the potential to be integrated into a variety of projects spanning from basic to progressively intricate in scope. Just to name a few, Arduino Mega was used in projects such as: Autonomous Underwater Vehicle used for Deep Sea Exploration [2], Wirelessly controlled Underwater Robot [3], Remotely Operated Vehicles [4], and a Miniature Autonomous Submersible [5].

For scientists to be able to conduct their underwater projects, they must come up with solutions to protect the microcontroller, as any amount of water can produce a short-circuit on the board, thus making it unfunctional. In cases where the microcontroller serves as a driving system controller for the device, an unresponsive microcontroller would make the retrieval of the device challenging, depending on what the depth of the device is when the microcontroller stops working.

In a paper made available by a group of scientists from Australia, they described the design process of a ROV that used Arduino Mega as a controller for the driving system [4]. The microcontroller and the rest of the hardware were placed inside a metallic housing (see Fig. 1), that was later sealed and fixed inside the ROV. The flaw of this solution is that the microcontroller is not perfectly fixed, and a dynamic shock could permanently damage the microcontroller.

In another paper made available in 2014 [5], a team of scientists took a different approach when designing a miniature autonomous submersible (MAS). They fixed the microcontroller and the rest of the hardware on a plain surface (see Fig. 2) and relied on the device’s outer surface to protect the microcontroller against the water.

A group of young scientists from the Palos Verdes Institute of Technology [6] used a watertight cylindrical chamber (see Fig. 3) to store the microcontroller and all the hardware that was necessary for the devices to function properly. However, this solution does not protect the microcontroller from dynamic shock damage, caused by external factors.

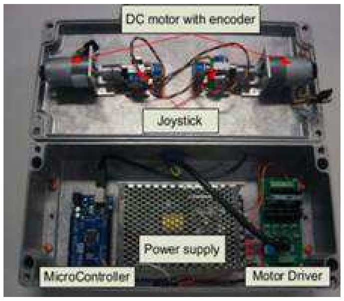


Fig. 1. Hardware of the haptic driven system within the joystick. [4]

Fig. 2. MAS hardware configuration. [5]

Fig. 3. Nautilus II hardware configuration. [6]

As already presented, the existing protective methods have flaws such as the microcontroller not being perfectly fixed within the system, which makes it susceptible to shock damage.

The microcontroller also doesn’t have a back-up protection against water, and thus, a short-circuit can appear in case the main waterproof method of the system fails.

Based on the requirements that were extracted from the scientific papers, a list of initial design conditions for a protective case has been created. The flaws presented earlier will be avoided, as the case has a fixing method, and is also waterproof. To prevent physical damage, the protective case should also be shockproof. In the end, additional features to make the case more user-friendly (such as processor cooling, DC connectivity, USB connectivity) have also been considered.

In this paper, the design of a new protective case that meets all the requirements above has been presented in detail. The main design challenge in the design process of the case was sealing and closing the case with low clearance. Additionally, the contact area of the heat sink present on the top part needs to press against the microcontroller to ensure effective heat transmission to the fins of the heat sink.

2. DESIGN PRESENTATION

2.1 Manufacturing Method

To be able to produce the protective case in mass, and make it available for the broad public, die casting has been selected as the manufacturing method for the protective case.

The following die casting rules have been respected in the design process:

a. Wall thickness is constant at 4mm, thus ensuring that the molten material cools down and shrinks evenly.
b. Walls are drafted at 2°, so the casted parts can be easily ejected from the die.
c. Corners have been rounded (see Fig. 4) to prevent the development of stress concentrators.

2.2 Elements for increasing the case’s resistance against high pressure.

As mentioned in point 2.1, the corners have been rounded for both the upper and the lower parts to prevent the development of stress concentrators. This design feature also has an impact on the case’s capacity to withstand the high pressures deep underwater.

To increase this capacity even further, reinforcement ribs were added on the interior of both parts (see Fig. 4). The reinforcement ribs are shorter on the lower part (5 mm), and taller on the upper part (15 mm). Taller reinforcement ribs are needed on the upper part as it's prone to deformation due to its increased height.

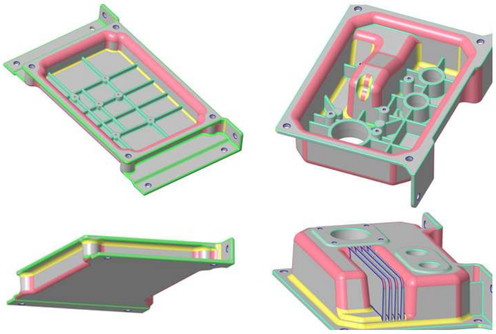
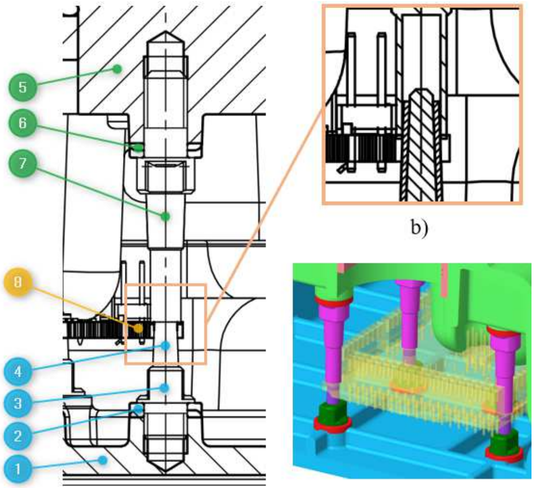


Fig. 4. Rounded corners and reinforcement ribs on the lower part (left) and the upper part (right).

2.3 Arduino Mega fixing method

As Arduino Mega has six fixing holes that can be used to position the board, six fixing domes with threaded holes were designed on both the lower and upper part (see fig. 5 a). Into the threaded holes of the lower part (1), a fixing pin (3) with a rubber gasket (2) is fastened. The fixing pin has a conical rubber gasket (4) on which Arduino Mega (8) is being positioned. The rubber gaskets have the purpose to help the positioning of the board, as well as to prevent the board from suffering shock damage. Additionally, the conical rubber gasket (4) has the purpose to ensure that the board is perfectly positioned into the case with low clearance.



b)

Fig. 5. Arduino Mega fixing method: a) lower pin and upper pin holding the board in place, b) cross section, c) arduino mega in a fixed position.

The upper part (5) also uses six fixing domes with threaded holes, on which the upper pin (7) and a rubber gasket (6) is being fastened. As the upper assembly is positioned on top of the lower one, the upper pin (7) applies pressure on top of Arduino Mega (8) and pushes it against the lower pin (3) (see in Fig. 5 b) and the conical rubber gasket (4) respectively.

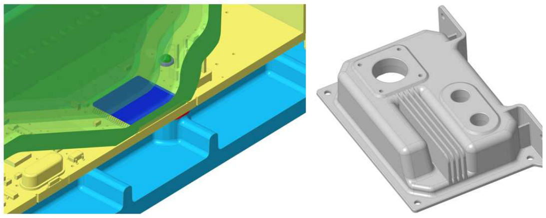
Assembling all six fixing pins (see Fig. 5 c) ensures that the board is fixed in place, and prevents the board from suffering shock damage, as it's incapable of hitting the protective case's walls.

2.4 Microprocessor Cooling Method

When Arduino Mega runs processes in an enclosed space, and the generated heat has no way to dissipate into the outer environment, the microprocessor is prone to overheating. This problem needs to be solved because irreversible damage can occur if the microprocessor overheats. To solve this problem, a heat sink was designed on the upper part. As the lower part and upper part are brought together, the inferior portion of the heat sink, called contact area, presses against the microprocessor (see Fig. 6 a).

The heat of the microprocessor is transferred to the heat sink present on the upper part with the help of a thin layer of thermal paste present between the two.

The heat is then transferred to the heat sink's fins which dissipate the heat into the environment. The heat sink has four fins (see Fig. 6 b), all having simple shapes, and they are not taller than the protective case itself to prevent collision with external objects.



a) b)

Fig. 6. Heat sink: a) upper part's contact area pressing against the microprocessor, b) shape of the fins.

2.5 Waterproofing Method

To enable the user to use Arduino Mega in underwater projects, the protective case was designed to be waterproof even at great depths.

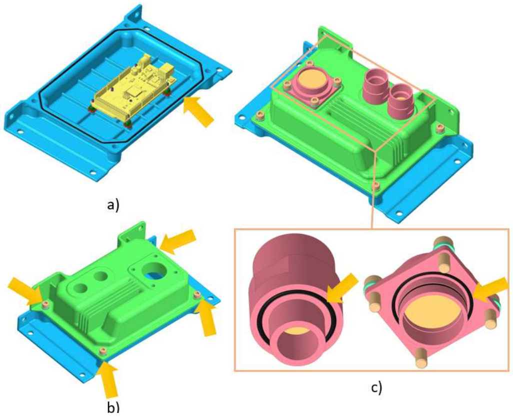


Fig. 7. Waterproofing method: a) rubber seal positioned in the lower part's groove, b) position of the screws, c) rubber seals of the main connector (bottom right) and secondary connectors (bottom left).

This was ensured by adding a rubber seal between the upper and the lower case (see Fig. 7 a). The connector holes are also sealed with the help of the rubber seals that are mounted onto the connectors by the supplier. The rubber seal is placed into the lower case's groove channel. The upper case is placed on top of it and brought together by fastening four M8 screws (see Fig. 7 b).

The pressure applied on the rubber seal forces it to deform into the groove channel, thus sealing the protective case. The main pins connector uses the same principle for ensuring the seal of the connector hole (see Fig. 7 c).

As for the DC and USB connectors, they come with rubber seals from the supplier (see Fig. 7 c). The sealing of these holes is produced when the connectors are completely fastened into the upper case.

2.6 Pins, DC power, and USB Connectivity

To enable the user to access all the features of Arduino Mega without having to disassemble the protective case, three connectors provided by TE Connectivity were added to the upper part (see Fig. 8).

The pins (1) are connected through jumper cables (2) to the main connector (3). The power socket (4) and USB (6) are connected through cables (5, 7) to the secondary connectors (8).

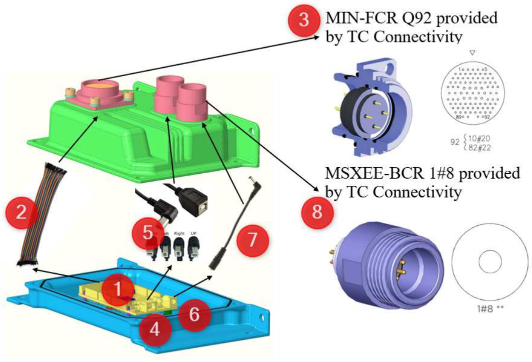


Fig. 8. Connectivity method.

3. FINITE ELEMENT ANALYSIS

3.1 Static Simulation

After the design process, the upper part was tested through the finite element method to see what is the maximum depth that the protective case can withstand. The reason why the upper part was chosen for this simulation is due to its shape, as it can break under the external forces much quicker than the lower case. The chosen material for the case is Aluminum A380, as it's one of the most suitable materials for Aluminum Die Casting, while still maintaining good strength [7]. Aluminum A380 has a Yield Strength of 159MPa. Results of the simulation showed that the maximum admissible depth of the Aluminum case is 36m (see Fig. 9 a). Identical simulations were repeated for a stronger material: Casted Ductile Iron (Yield Strength – 276MPa [8]). Results of the simulation showed that the maximum admissible depth of the Casted Ductile Iron case is 63m (see Fig. 9 b).

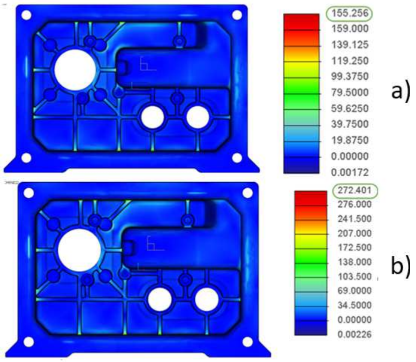


Fig. 9. Simulation results: a) Aluminum A380, b) casted ductile Iron

Based on the Static simulation results, significant stress concentrators can be found between the reinforcement ribs and the inner walls of the upper protective case (see Fig. 10). This problem can be solved by increasing the width of the reinforcement rib and increasing the value of the rounds. Using more reinforcement ribs should also be considered to increase the maximum admissible depth of the case. Additionally, higher ribs are needed, as critical stress points appear on the walls of the protective case. To be able to reach greater depths, using other manufacturing methods to and more intricate designs can also be considered.

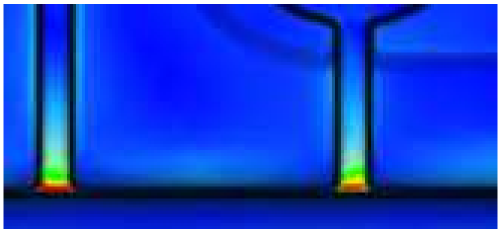


Fig. 10. Maximum deformation

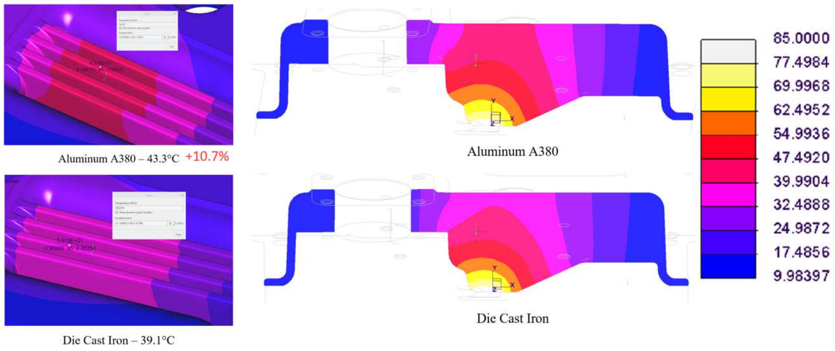
3.2 Thermal Simulation

To test the efficiency of the heat sink, two thermal simulations were run on the upper case. The upper case was tested at normal conditions (1bar and 10°C), as the heat dissipates much easier when the device is submerged underwater. First, the boundary conditions were set. According to [9], the convection coefficient during free air flow varies between 2.5-25 W/(m^2*K). For this simulation, a value below average was chosen, and the convection coefficient of the heat sink fins and the surfaces surrounding it was set at 10 W/(m^2*K).

The prescribed temperature at the contact area between the microprocessor and the heat sink was set as 85°C, to simulate the maximum admissible temperature recommended by the supplier. Temperatures beyond the maximum admissible temperature would result in permanent damage to the microprocessor.

As expected, the heat dissipates more effectively for the aluminum case, as compared to the one made of die cast iron. As shown in Fig. 11 a, the maximum temperature reached on top of the Aluminum heat sink's fins is 43.33°C. In comparison, the maximum temperature reached on top of the die cast iron's heat sink's fins is 39.15°C. To analyze the effectiveness of the heat sink even further, one fin of the heat sink has been cross-sectioned, and the result can be seen in Fig. 11 b. As the heat does not distribute evenly on the entire surface of the heat sink's fins, it was concluded that the costs of the protective case can be reduced by reducing the length of the fins. Additional simulations should be considered to determine if this change is feasible or not.

Aluminum A380 dissipates heat 10.7% more efficiently than die cast iron, and thus it's more favorable to use Aluminum A380 as the manufacturing material for the protective case, due to its increased heat transfer capability.



a) b)

Fig. 11. Thermal simulation results: a) maximum temperature, b) cross section of the result.

4. CONCLUSIONS

To ensure the normal functioning of an Arduino Mega board that's being used at underwater applications, in this paper, the design process of a new protective case has been presented in detail.

The design solved all the initial flaws that were identified by reviewing scientific papers made available by academics that used Arduino

Mega in underwater projects. The upper part was then analyzed through Finite Element Analysis to determine what is the maximum admissible depth, and to see how effective the heat sink is.

After the static simulation it has been concluded that the Die Cast Iron case can be submerged to 75% greater depths as compared to the Aluminum A380 case. On the other hand, after the thermal simulation it has been concluded that the Aluminum A380 case is 10.7% more efficient in transferring heat as compared to the Die Cast Iron case.

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CERCETĂRI PRIVIND PROTEJAREA MICROCONTROLLER-ULUI ARDUINO-MEGA UTILIZAT ÎN EXPLOATĂRI ACVATICE

Rezumat: Oamenii de știință caută constant metode efciente pentru a face explorarea acvatică mai accesibilă și mai sigură. De-a lungul anilor, cercetătorii au început să utilizeze microcontrolerul Arduino Mega pentru proiectele lor datorită versatilității, costului redus și capabilității de a fi folosit în proiecte complexe. Obiectivul acestui articol este proiectarea unei carcase impermeabile pentru microcontrolerul Arduino Mega care sa reziste la condițiile impuse de explorările acvatice. Testele FEA vor supune carcasa progresiv la diferite adâncimi, urmată de simulări termice pentru a testa eficiența radiatorului. În final, carcasa va fi capabilă să protejeze microcontrolerul și toate componentele lui împotriva deteriorării cauzate de lovituri, și totodată permite utilizatorului să acceseze toate funcțiile microcontrolerului fără să fie nevoit să deschidă carcasa. Aplicațiile practice ale acestui articol pot fi utilizate de către oricine, de la entuziaști și amatori la cercetători, pentru a crea sisteme noi care pot explora în continuare fundul oceanului.

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