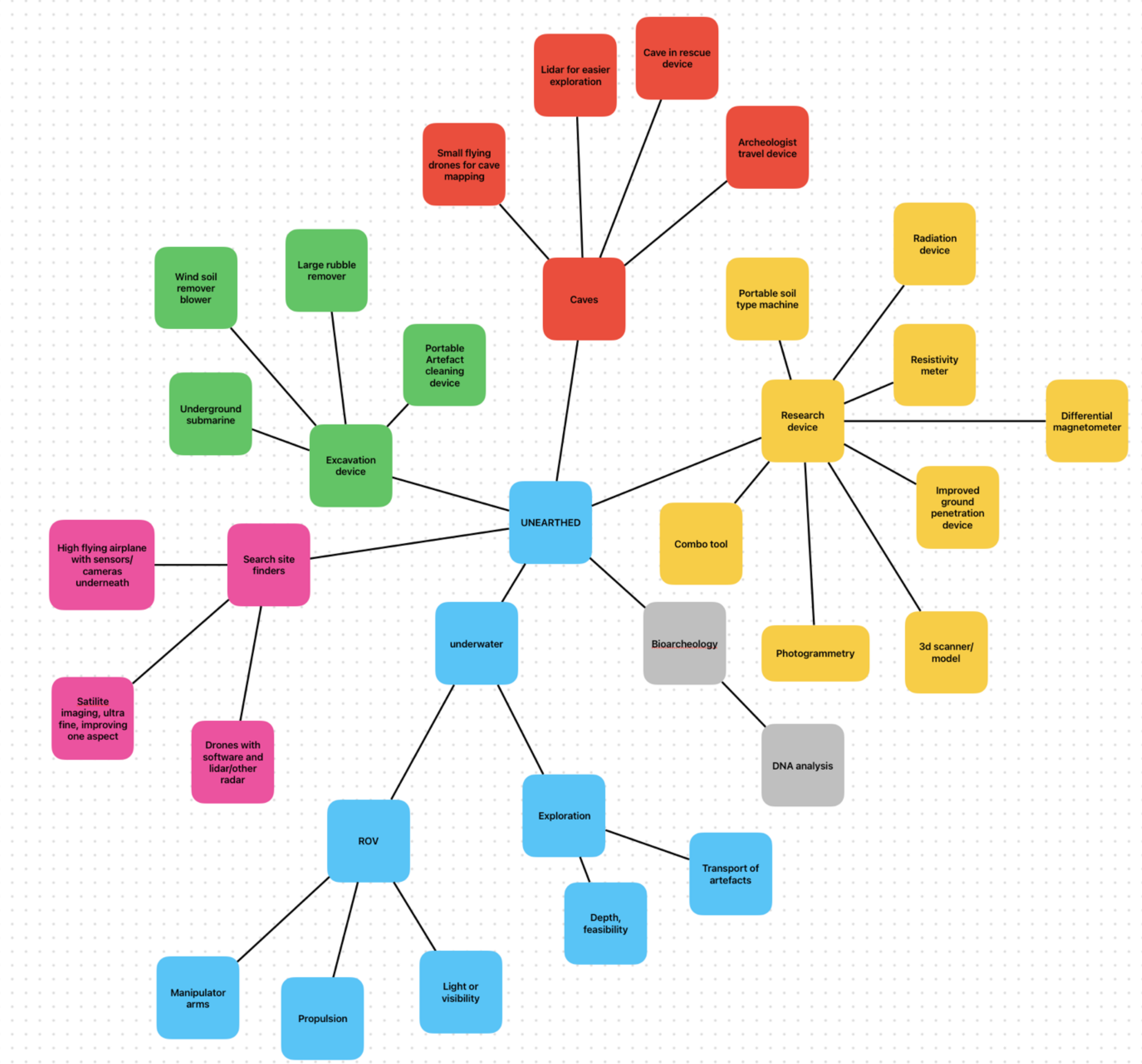
Team LEBOB's

Innovations

2025 Unearthed

Members:
Kingsley Wong
Sean Chan
Oliver Liu
Leven Shi
Subesh Sukumaran
Yuxin (Chris) Wang
Aaron Zhang
Andre Nijman

Brainstorm



As a team, we had a couple of different preferences. We would have liked to do something that was coding related as well as mechanical, and which involved electronics. However, as a team we were flexible and didn't really mind what we did. We ultimately decided upon manipulator arms, as they are a rapidly improving field, that was doable to a group of school students that had, at their disposal, 3D printers and basic electronic parts.

Problem

Underwater archaeologists struggle to recover fragile artefacts from the seafloor because most ROV manipulator arms are designed for industrial work, not precision handling. These arms usually have two rigid metal fingers, no sensitivity control, and limited surface contact. That makes them clumsy when grabbing small, irregular or brittle objects. Archaeologists also suffer from equipment failures, and breakages can cost millions of dollars, with the delivery costs.

Because of that, archaeologists face three major issues:

1. High risk of breakage. Industrial grippers apply too much force with no feedback, so thin pottery, coral, bone fragments and delicate shapes often crack.

2. Poor grip on odd shapes. Flat jaws can't adapt to curved, tapered or uneven artefacts, so many items simply slip out or can't be lifted at all.

3. Limited awareness for pilots. Operators can't feel how much force the arm is applying, especially in low-visibility environments, which leads to accidental crushing or drops.
4. Cost and time pressures. Archaeology generally takes millions of dollars to move all the equipment from a facility over onto a ship, then travelling over to the site. If any equipment breaks, or they didn't bring the right tool, then they may have to wait the delays while the tools arrive. These failures slow down missions, increase costs, and can permanently destroy cultural heritage. Archaeologists need a tool that have been designed for fragile artefacts, not repurposed from oil and mining industries.

Research

Websites

Assessing damage and predicting future risks: A study of the Schilling manufactured Titan 4 seven function manipulator during 2017 - 2022 – DONE
https://www.sciencedirect.com/science/article/pii/S002980182302666

Collision Detection for Underwater ROV Manipulator Systems -
https://pdfs.semanticscholar.org/2327/89da0cdc7c8ff9b114b9383fc5ce8a49956a.pdf

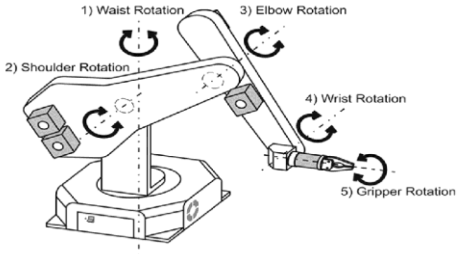
Underwater manipulators: A review – DONE
https://www.sciencedirect.com/science/article/pii/S002980181831030

Lightweight underwater robot developed for archaeological surveys and excavations - https://robomechjournal.springeropen.com/articles/10.1186/s40648-023-00240-4

https://www.imca-int.com/resources/safety/safety-flashes/0301-rov-personnel-injury/
Sivčev et al., 2018a; Bogue, 2015; Petillot et al., 2019; Antonelli, 2014

Notes

Underwater manipulators: A review
Notes: - Underwater manipulators are used in many ways: grasping, lifting, handling objects underwater - Factors that affect the performance of these include hydrodynamic effects (drag, added mass), buoyancy, structural stiffness, joint design, reach, torque, capability - Reach is also important - Manipulator arms are considered the most suitable tool for executing sub-sea operations - Majority of existing arms are anthropomorphic - Most arms are designed for a single purpose, ie lifting large, heavy objects, or attaching a gripper to an underwater object - Most working class ROVs have two manipulator arms, one simple, strong one to hold onto the object, and a smaller one to do the actual job - Most common materials used are metal alloys, including titanium Ti 6-4, anodized aluminum alloys (5083, 6082 T6, 6061 T6, 7075 T6, A356), stainless steel alloys (316, 630, 660), as well as some plastics (Polyethylene) - Key factors in those materials include high corrosion resistance, relatively high strength and ease of manufacturing - To reduce weight and actuator burden, buoyant materials have been tried - Commercially available arms typically are rated at 3000m to 6500m of sea water, however some can reach 7000m - Some have been developed for full ocean depths 11000 msw - size of underwater manipulators is described as a parameter called “reach” - represents the length of the whole manipulator kinematic chain - reach of existing underwater manipulators from 0.5 m up to 2.4 m - max wrist torque ranges from 8Nm to 250Nm - listing and carrying vary from 5 kg to 500 kg - rotary low torque rated for max of 75 Nm - manipulator arm weight in air varies from 6kg to 150kg - commercial arms come with interchangeable grippers with specific purpose

- common gripper type is parallel acting jaws that has a slot for a standard T-bar handle
- primary function to grip a variety of different objects and tools
- different grippers include three/four finger intermeshing jaws, two/three finger floating jaws, scissor jaws, suction foots
- grippers are usually hydraulic
- grip strength range from 35 kgf to 652 kgf
- both experimental and commercial arms have between 3 to 6 degree of freedom (DOF)
- 

Example of a 5 DOF manipulator arm
- reason for this is that 3 DOF is sufficient for achieving arbitrary position and 6 is sufficient for achieving both arbitrary position and orientation of the end effector
- term “n-function” generally used to describe number of actuators used, one for the gripper and the rest for arm movement
- underwater arms with 7 or more DOFs, not including gripper actuator, are not very common, but do exist
- True 7 DOF manipulator arms are said to be inherently redundant from a kinetic standpoint
- This can be used later for redundancy or to achieve secondary objectives
- Benefits of sea water hydraulic operated manipulator arms include : low viscosity, high power density, non-flammable properties and zero environmental impact
- Disadvantages: corrosive and abrasive properties, lubrication and sealing issues, unsuitable working temperature range, etc
- All existing manipulator arms now either use oil hydraulic or electricity, both of which have advantages and disadvantages
- Proposed dual, both oil and electricity, however not commercially viable yet
- Biodegradable oil has now minimized the impact of fluid leaks
- Generally, hydraulic actuators can produce an output force/torque much larger than the force applied on the input without the use of mechanical components such as gears and levers (direct drive)
- They are a necessity for the implementation with electric actuators

- Thus, hydraulic systems have higher power to weight ratio (payload capability) which goes up to the order of three for the existing commercial hydraulic underwater manipulators
- Whereas ratio is one or less for the electrical ones
- Hydraulic benefits lead to majority of commercial arms being hydraulic
- Actuators with limited motion e.g. piston cylinders and rotary vane actuators are used to drive manipulator joints
- Some cases gearmotors, type of hydraulic motor with continuous motion are used for wrist joint actuation
- Hydraulic manipulator arms suffer from poor positional accuracy compared to electric arms, and are not suited for fine control of the interaction force with the environment during contact tasks
- Another problem is fluid leaks, which is almost impossible to solve, which brings demand for higher quality material and construction, resulting in higher prices
- Also, hydraulic arms require additional infrastructure, like pumps and tanks, while electric don't, requiring only electricity which can already be found
- Electric arms are less frequent in commercial use, however are often used for experimental or custom made arms
- Actuators commonly use brushless DC motors, with large reduction ratios
- To stop water ingress, oil is used, which also helps with lubrication and cooling
- To prevent using external wires that could result in possible entanglement, power and signal cables are fed through the same hoses used for pressure compensation
- Main advantage of electric arms are its precision and force/torque control
- Most aren't used in operations as they lack the speed, reliability and strength requirements
- Different types of operating systems
- One which has each actuator/joint as a different input-output system, which combined to control the entire arm, this is known as a decentralized control scheme
- The second type is the opposite, a centralized control scheme, which takes dynamic interactions between the joints into account
- When designing a control system, you need to take into consideration the specifics of your ROV as your drive system, different actuators, etc can impact the control system, if you're using a hydraulic system, the viscosity of the oil and its pressure and flow can
- It is extremely difficult to model and control a manipulator arm, as hydrodynamic effects such as buoyancy, drag and lift forces as well as

external forces like waves, currents etc all can affect manipulator arms. The temperature, depth, salinity, etc can also affect the hydrodynamic affects as well as the arm itself - Control schemes which integrate proportional (P), integral (I) and derivative (D) terms in different variations offer simplicity of implementation and low software costs
Reference https://www.sciencedirect.com/science/article/pii/S0029801818310308

Assessing damage and predicting future risks: A study of the Schilling manufactured Titan 4 seven function manipulator during 2017 - 2022
Notes: - Leaks or damage to the seals of the manipulators arms are the most common cause of damage - The jaws or fingers of the manipulator arms are the element most exposed to damage - There is a correlation between operator errors and manipulator damage - It is possible to identify possible preventative measures against future failures - The Titan 4 is the most widely employed equipment on work class ROVs world wide - Depth for scientific work can go between a few meters underwater to 10,000 m (Cochran, 2019; Kennish, 2019). - only around 5% of ROV shares are used for scientific research - Underwater Vehicle Manipulator Systems (UVMS) typically resemble human arms and have interconnected rigid arms with revolute joints and end-effectors like grippers and tools - Often also have cameras or lights - designed for different purposes, such as lifting heavy objects, attaching detachable grippers to sunken objects, fixing underwater vehicles to structures or walls, inspection tasks, dexterous intervention operations, and more - Work class ROVs typically have two manipulators, with one serving to hold the ROV near the structure while the other performs the actual intervention task (Sivčev et al., 2018a) - Tasks executed by underwater manipulators include .... biological and geological sampling, archeological work, and more - Most manipulator arms are located at the front, but some can be found located in the back - Most are operated by pilots and co-pilots, however limited visibility in murky waters and poor camera angles can lead to collisions and significant damage - A collision detection mechanism has already been developed

- Titan 4 has good corrosion resistance, a key factor for underwater mechanical mechanisms
- Key parts of the Titan 4 include azimuth, shoulder, upper arm, elbow, forearm, pitch & yaw, wrist, and jaw

Reference: https://www.sciencedirect.com/science/article/pii/S00298018230266

Analysis of Lightweight Materials for Robot Manipulators

Notes:

- Aluminum is widely used for manipulators, because of its good mechanical properties
- For industrial robot designs, a material with low density and high rigidity is preferred
- Composite materials often can perform better than aluminum, however, are more expensive and difficult to manufacture
- Comparison between aluminum and a carbon fiber composite

Table 1: Material comparison

Material	Mechanical properties	
	Density (kg/m3)	*Elastic Modulus (GPa)*
Aluminum 6063 – T6	2700	70
Carbon Fiber (70%) Composite	1600	140

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- Traditional heavy rigid arms are designed with stiff links, so the links dynamics can be ignored, and the position of the entire arm can be found through the positions of the actuators
- In flexible robots the links are no longer assumed to be rigid, so when there is movement, unwanted vibrations may change the position of the arm and tip, making positional errors more likely

Reference: https://www.ajbasweb.com/old/ajbas/2015/May/877-882.pdf

Materials for ROVs – Top 5

Notes:

- **Anodized aluminum**
- **Benefits**: corrosion resistance, durability, relatively light,
- **Drawbacks**: may not be suitable to deep-sea applications where more durable materials like titanium would be preferred, coating may rub off in abrasive conditions
- **Titanium**
- **Benefits:** exceptionally strong, low weight, corrosion resistance, excellent fatigue resistance, can withstand high pressure and aggressive fluids

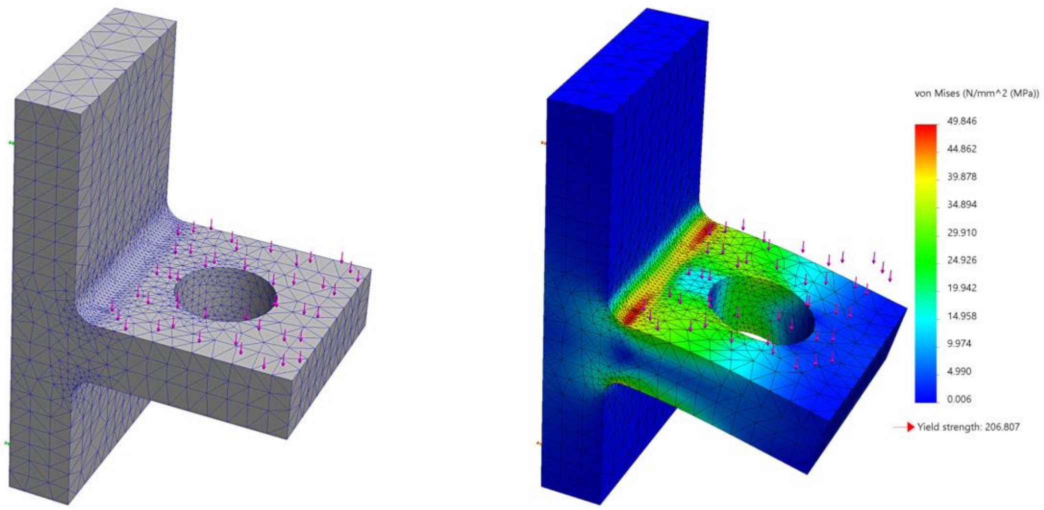
- **Drawbacks:** much more expensive than aluminum, fabrication can be more complex, large carbon and environmental footprint
- **Stainless steel**
- **Benefits:** corrosion resistant, good strength
- **Drawbacks:** much heavier than other options, may require additional treatments to make for optimal corrosion resistance
- **Plastics and composites**
- **Benefits:** good balance of weight, strength and corrosion resistance, can insulate against electricity, good seals
- **Drawbacks:** limited high temperature resistance, limited depth capacity, not suitable for deep sea applications
- **Ceramics**
- **Benefits:** excellent corrosion resistance, wear resistance and thermal stability
- **Drawbacks:** brittle and require careful engineering to prevent failure under mechanical stress or impacts, least versatile and very rare to see ceramics in main body of ROV, more in specialized applications like sensors
- **In General:**
- Materials that are needed in ROVs typically require three main properties:
- Corrosion resistance, the sea is extremely salty and can rust or damage materials if submerged for enough time
- Strength, deep sea pressures or impacts with creatures or rocks can damage structural elements, which can lead to malfunctions or at worse, water leaking into the electronics, resulting in an unusable ROV
- Low weight, less weight requires less energy to move in water, making the ROV more energy efficient, and reducing the amount of power the movement motors require, giving more to the main manipulator arms.

Reference: https://seamor.com/materials-for-rovs-top-5/

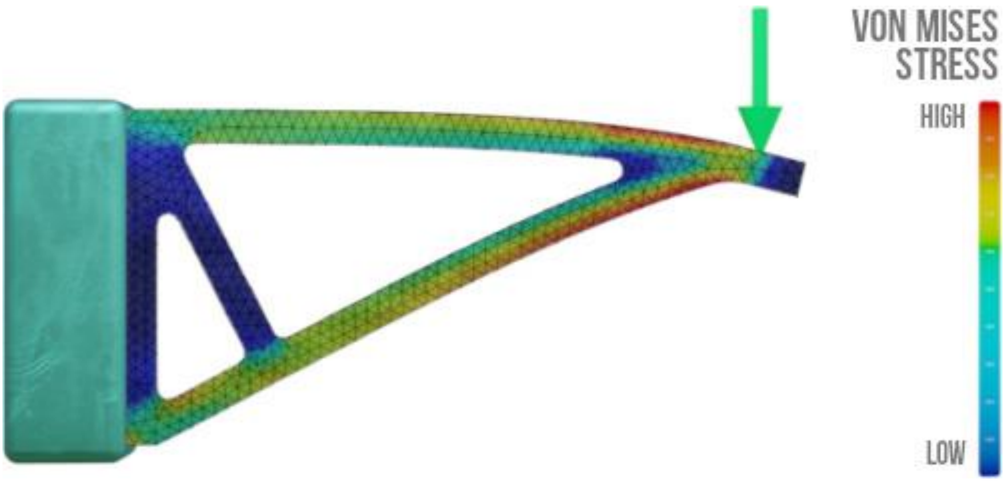
Finite Element Analysis:

Finite Element Analysis is a computational method that uses software to predict how a physical object will react to real-world forces, vibrations, heat, and fluid flow by breaking it down into millions of small finite elements. By applying mathematical equations to each element and then combining the results, FEA allows engineers to simulate physical phenomena to test a product's performance, predict if it will break or wear out, and optimize its design without needing to create physical prototypes. It is widely used in industries like aerospace, automotive, and consumer products.

This process takes a long time which can limit reduce the feasibility of using Finite Element Analysis.



In the photo above, the red parts show where this part is most stressed and the blue parts show where the part if the least stressed. As the connection point is where the most stress occurs, you can see it bends a little downwards.



You can see above another example.

Our arm uses a 4 different arms with pressure sensors and foam pads that prevent breakage and failure of collection. Underneath is a photo of an FEA'ed 4 arm hand with different amounts of deformation

Due to this process of doing FEA being too long we do not have any info on our arm but we have some idea of what forces can affect

Specifications of existing manipulator arm models:

Table 1
Specifications of existing commercial underwater manipulators.

Manufacturer	Model	Actuation	DOF	Weight in air [kg]	Weight in water [kg]	Lift capacity max nom. (full ext.) [kg]	Wrist torque [Nm]	Grip force [kgf]	Depth rating [m]	Max. reach [m]	Power Source	Material	Actuators	Sensors	Control	Price [$]
Ansaldo	MARIS 7080	Electric	7	65	45	8 (/)	/	20.4	6000	1.4	72VDC	Al	BLDC	Resolvers, F/T	Semi Automatic	/
Cybernetix	Maestro	Hydraulic	6	85	65	100 (96)	190	150	6000	2.4	50 Hz 220VAC 210bar 18lpm	Ti	Rot. vane & gerotor	Resolvers	Pos. & force fb.	~1m
Eca Hytec	Arm 7E	Electric	6	69	49.2	40 (40)	25	80	6000	1.79	24-36VDC	Al 6082 T6	BLDC in oil	/	Prop. & torque	~110k
Eca Hytec	Arm 7E Mini	Electric	6	51	30	25 (25)	25	50	3000	1.44	24-36VDC	Al 6082 T6	BLDC in oil	/	Prop. & torque	~110k
Eca Hytec	Arm 5E	Electric	4	27	18.5	25 (25)	25	60	6000	1	24-30VDC	Al 6082 T6	BLDC in oil	/	Prop.	~40k
Eca Hytec	Arm 5E Mini	Electric	4	23	15	25 (25)	25	50	6000	0.85	24-40VDC	Al 6082 T6	BLDC in oil	/	Prop.	~40k
Eca Hytec	Arm 5E Micro	Electric	4	10	2.7	10 (10)	10	50	6000	0.64	24-30VDC/240VAC	Al 6082 T6	BLDC in oil	/	Prop.	~25k
Forum Perry	TA40	Hydraulic	6	98	65	125 (210)	150	509	11000	2	No electrical 210bar 9lpm	Al, SS	Cylinders, rot. vane & gerotor	No	Pos./Rate/ Hybrid fb.	/
Forum Perry	TA60	Hydraulic	4	82	60	380 (300)	250	509	11000	1.44	No electrical 210bar 9lpm	Al, SS	Cylinders, rot. vane & gerotor	No	Rate/Hybrid fb.	/
Forum Perry	TA60J	Hydraulic	4	76	51	380 (300)	250	509	11000	1.38	No electrical 210bar 9lpm	Al, SS	Cylinders, rot. vane & gerotor	No	Rate/Hybrid fb.	/
Forum Perry	TA16	Hydraulic	4	50	40	147 (102)	108	226	11000	1.06	No electrical 210bar 9lpm	Al, SS	Cylinders, rot. vane & gerotor	No	Rate/Hybrid fb.	/
Graal Tech	UMA	Electric	6 (7)	28	14	10 (/)	/	/	100	1	24VDC	Al	BLDC	Yes	Position	~75k
Hydro-Lek	40400	Hydraulic	4	45	30	150 (210)	75	/	11000	1.42	210 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~16k
Hydro-Lek	40500(R)	Hydraulic	6	59	40	150 (210)	75	/	11000	1.5	210 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~30k
Hydro-Lek	43000	Hydraulic	4	6	4	10 (20)	8	/	11000	0.53	160 bar	SS 316, PE	Cylinders & gerotor	No	Rate	~4k
Hydro-Lek	CRA6	Hydraulic	5	28	14.5	32 (32)	38	/	11000	1.5	140 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~12k
Hydro-Lek	EH5	Hydraulic	4	12	9.5	25 (25)	14	/	11000	0.8	140 bar	Al E30, SS 316	Cylinders & gerotor	No	Rate	~7k
Hydro-Lek	HD5	Hydraulic	4	21.5	16.5	40 (40)	38	/	11000	0.819	140 bar	SS 316, Al HE 30, PE	Cylinders & gerotor	No	Rate	~9k
Hydro-Lek	HD6W HD6R	Hydraulic	5	29	21	40 (40)	38	/	11000	1.12	140 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~12k
Hydro-Lek	MB4	Hydraulic	3	13.3	11	40 (40)	40	/	11000	0.63	140 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~5k
Hydro-Lek	RHD5(W)	Hydraulic	4	30	20	80 (80)	38	/	11000	0.95	210 bar	SS 316, Al HE30, PE	Cylinders & gerotor	No	Rate	~11k
ISE Ltd.	Magnum 7	Hydraulic	6	63.5	30	454 (295)	108	205	11000	1.5	70bar 19lpm	Al, SS	Cylinders	Potentio-meters	Pos./Rate	~59k
ISE Ltd.	Magnum 5	Hydraulic	4	50	27	454 (295)	108	160	5000	1.16	70bar 19lpm	Al, SS	Cylinders	Yes	Pos./Rate	~52k
ISE Ltd.	Magnum 6 Mini	Hydraulic	5	57	30.6	454 (317)	108	160	5000	0.96	70bar 19lpm	Al, SS	Cylinders	No	Rate	~56k
ISE Ltd.	Magnum 5 Mini	Hydraulic	4	34	24	68 (23)	14	35	5000	0.71	35bar 19lpm	Al, SS	Cylinders	No	Rate	~46k

Table 1 (*continued*)

Manufacturer	Model	Actuation	DOF	Weight in air [kg]	Weight in water [kg]	Lift capacity max nom. (full ext.) [kg]	Wrist torque [Nm]	Grip force [kgf]	Depth rating [m]	Max. reach [m]	Power Source	Material	Actuators	Sensors	Control	Price [$]
KNR Systems Inc.	HYDRA UW3	Hydraulic	6	130	/	300 (121)	350	300	500	2.035	210bar 19lpm	Al, SS, Ti	Cylinders & rotary vane	Encoders	Position	~175k
Kraft	Predator	Hydraulic	6	80	51	227 (91)	135	135	6500	1.64	50 Hz 220VAC 210bar 19lpm	Al, SS	Cylinders, rot. vane & gerotor	Yes	Pos. & force fb.	~200k
Kraft	Raptor	Hydraulic	6	75	44	227 (91)	135	135	6500	1.52	50 Hz 220VAC 210bar 19lpm	Al, SS	Cylinders, rot. vane & gerotor	Yes	Pos. & force fb.	~200k
Kraft	Grips	Hydraulic	6	59	41	82 (45)	20	90	3000	1.556	50 Hz 220VAC 210bar 11lpm	Al, SS	Cylinders, rot. vane & gerotor	Yes	Pos. & force fb.	~200k
Ocean Innovation System	BE5-500	Electric	4	15	8	/(16)	1.6	100	500	0.7	24 VDC	Al 5083, PE	BLDC	Hall	Rate	~30k
Oceaneering	Atlas Hybrid	Hydraulic	6	73	50	454 (250)	205	454	6500	1.66	90-260VAC 206bar 19lpm	Al 6061 T6, SS	Cylinders, rot. vane & gerotor	Solid State Pos.	Hybrid Pos./ Rate	/
Profound Technology	M1P	Hydraulic	6	115	77	275 (250)	175	652	4000	2.1	/	Al, SS	Cylinders & rotary	Yes	Pos./Rate	/
Schilling	Titan 2	Hydraulic	6	80	61	/(109)	68	136	6500	1.92	90-260VAC 210bar 19lpm	Ti	Cylinders, rot. vane & gerotor	Resolvers	Pos. & force fb.	/
Schilling	Titan 3	Hydraulic	6	/	/	/(/)	/	/	6500	1.92	90-260VAC 210bar 19lpm	Ti	Cylinders, rot. vane & gerotor	Resolvers	Pos. & force fb.	/
Schilling	Titan 4	Hydraulic	6	100	78	454 (122)	170	417	7000	1.92	90-260VAC 210bar 19lpm	Ti	Cylinders, rot. vane & gerotor	Resolvers	Pos. & force fb.	/
Schilling	Conan 7P	Hydraulic	6	107	73	273 (159)	205	454	3000	1.8	90-260VAC 210bar 19lpm	Al 6061, SS	Cylinders, rot. vane & gerotor	Potentio-meters	Pos.	/
Schilling	Orion 7P/ 7R	Hydraulic	6	54	38	250 (68)	205	454	6500	1.85	90-260VAC 210bar 19lpm	Al, SS	Cylinders, rot. vane & gerotor	Potentio-meters	Pos./Rate	/
Schilling	Atlas 7R	Hydraulic	6	73	50	500 (250)	205	454	6500	1.66	90-260VAC 210bar 19lpm	Al 6061 T6, SS	Cylinders, rot. vane & gerotor	No	Rate	/
Schilling	RigMaster	Hydraulic	4	64	48	270 (181)	205	454	6500	1.37	No electrical 210bar 19lpm	Ti, Al, SS 630	Cylinders, rot. vane & gerotor	No	Rate	/
Schilling	Orion 4R	Hydraulic	3	30	21	136 (/)	205	454	6500	0.68	No electrical 210bar 19lpm	Al, SS	Cylinders rot. vane & gerotor	No	Rate	/
Seamor	7F-H-ARM	Hydraulic	6	32	/	/(5)	/	/	300	1.07	300V 35bar 4.5lpm	SS 316, Al 6061 T6	/	/	/	/
TitanRob	M700	Hydraulic	6	30	20	50 (40)	45	80	3000	1.05	140 bar min 1.5lpm	Ti, SS 316	Cylinders, rot. vane & gerotor	No	Rate	~45k
TitanRob	G500	Hydraulic	4	20	15	100 (80)	80	250	3000	0.8	140 bar min 1.5lpm	Ti, SS 316	Cylinders & rotary	No	Rate	~40k
TitanRob	M501	Hydraulic	4	14	11	50 (40)	45	80	3000	0.95	140 bar min 1.5lpm	Ti, SS 316	Cylinders & rotary	No	Rate	~35k

Solution

Our design upgrades the standard ROV gripper by combining three innovations that directly target the weaknesses found in current underwater arms, and sea based archaeology.

1. Adaptive soft-contact finger pads

- We add flexible foam pads to each fingertip so the arm no longer presses metal against artefacts. The soft pads spread the gripping force across a wider area, which lowers stress on fragile material. This reduces breakage risk and lets the arm safely handle smooth surfaces like vases, curved bones or rounded stone fragments.

2. Embedded pressure-sensing system

- Under each foam pad is a calibrated pressure sensor. These sensors constantly measure how strongly the gripper is squeezing. The readings go straight to the pilot, and optionally into our auto-stop control code, which halts the actuator the moment pressure passes a chosen limit. That means operators finally get an early warning before damaging something and can set safe pressure presets for different artefacts such as coral, bone or clay.

3. Rotating finger platform for full-surface contact

- All pads and pressure sensors are mounted on a rotating plate. This lets the gripper automatically align its pads to match the angle of the artefact, so more surface area touches the object. Better contact means better grip, fewer drops, and more reliable handling of awkward shapes. Rotation also reduces how precise the ROV's positioning needs to be, making real-world operation easier and faster for pilots. This was unfeasible for our scaled down design, however on a 1 to 1 model, we would have incorporated it into the design.

4. A cheap, kit based modular claw

- This allows archaeologists to bring multiple copies of the claw on a mission, which reduces the chance of an equipment failure during the trip. As it is also made out of plastics, it allows archaeologists to bring a small 3D printer with them, allowing them to create custom grips and other tools when it is required, reducing the need for ship based transportation of tools and equipment. They can also print new tools for the claw, allowing for more adaptability during the mission.

Together, these four features turn a basic industrial gripper into an intelligent, adaptable archaeological tool. It protects fragile objects, improves pilot accuracy, and solves the biggest limitations of today's two-finger manipulators.

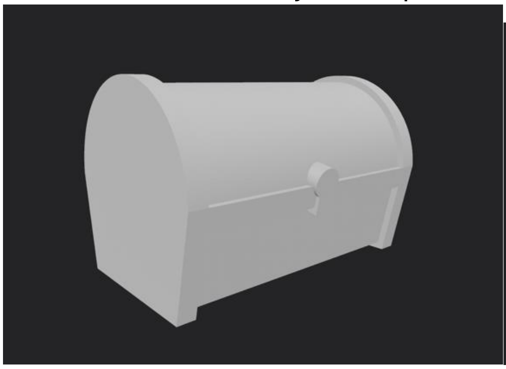
After Regionals

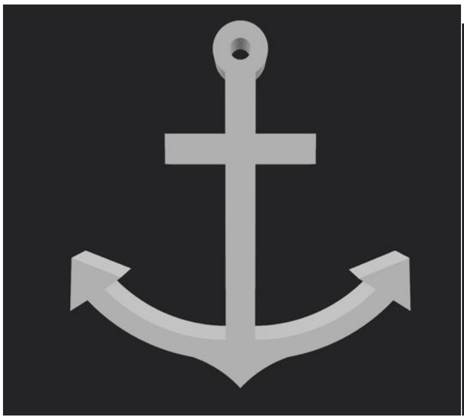
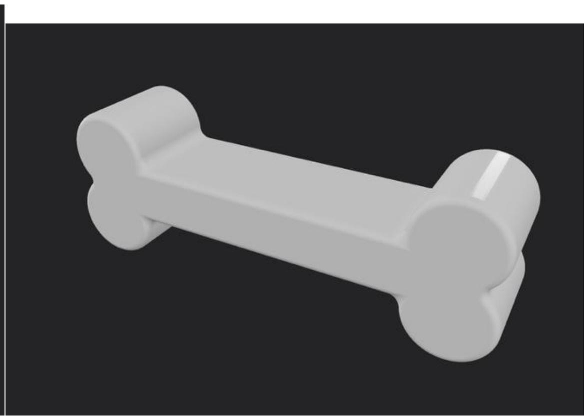
For our arm, we would originally planned to use titanium, or anodized aluminium, however after regionals, we called Tim MacDonald, a subsea engineer and deep sea ocean explorer. He said that titanium, or any metal, was too expensive for archaeology, and 3D printed parts were more accessible, easy to produce and less expensive. He recommended nylon 12 with carbon fibre, or any plastic that didn't absorb water or change its property in cold or wet environments. Thus, we changed our material from titanium to nylon 12 CF (carbon filled). It also is quite cheap, with 1k of filament costing around $100, in comparison to the $160 of titanium, if we compare the volumes.

We implemented the servo and pressure sensor into the claw to complete the prototype. We also planned to secure all the joints with nuts and bolts. We could also implement a barometer to measure the outside water pressure, which we would use to improve the accuracy of our pressure sensor.
We also thought about using a DC motor instead of a servo due to the torque requirements, however we would lose the ability to control our angle, making it more difficult to control.

Testing and Results

We used a set of 4 objects, a pot, a treasure chest, a bone and an anchor.



We chose this set of items because they are a diverse range of items, with different shapes and features. For example, the bone and the anchor are both quite long items, however one has two sets of holds that could provide grip for a manipulator arm, however the bone has little places to grip, besides the two ends. The chest and the vase are also quite similar, as they are both quite stout objects, however the chest is a rectangular object, with grooves in the side for quite easy grip, while the vase is a smooth, circular object, and only has the head portion to grip for the arm.

Object	Number of attempts (4 fingers)	Number of attempts (2 fingers)	Pressure values to grip
Bone	2	4	26 g f
Anchor	5	4	96 g f
Vase	3	5	411 g f
Chest	3	3	288 g f

Impact

Impact on Others

Our project would impact a wide variety of different professions and people. Other than the obvious, like an archaeologist, it could also impact engineering, science, infrastructure, oil, repair work, mining, and geography. It would help all of these professions in various ways, like improving the feasibility of doing work, the ease of doing work, and improving the ability to recover objects.

Impact on the Environment

Our innovations project allows for the easier retrieval of artefacts from places where damage may be caused, to the artefact or its surroundings. Using our project/claw will reduce risk of damage to environment, as well as make mistakes less costly. For example, if a scientist is trying to pick up a delicate coral piece, but they accidentally apply too much pressure, a normal manipulator arm might have crushed it. However, our soft foam pads would reduce the pressure and help the coral survive. We also use high quality and corrosion resistance materials, which reduces the chances of fluid leaks, preventing toxic fluids like oil from reaching the sea. This would reduce the chance of poisoning sea creatures.

Feedback

Changes made due to feedback

David Howard suggested a problem with our design. As the claw goes lower under the water, the outside pressure also increases. This could cause issues with the pressure sensing mechanism, reducing the reliability of the mechanism. To fix this, we add a pressure sensor to the main body of the claw, which would measure the outside water pressure. We would then use our code to cancel out the difference, resulting in the correct pressure readings.
Tim MacDonald brought up several key points to which we could improve on. He said that we shouldn't be using titanium or other materials like it, as they are expensive and heavy. Instead, we should use plastics, like the material that we used to create the prototype. Specifically, he suggested nylon 12 CF, or PTFE. He also suggested using a connector, to connect the grabber to the arm mechanism. He also suggested using a trick, using oil filled containers on our electronics to help resist the water pressure. This creates a cheap pressure seal, helping lower our costs even more. Finally, he helped us improve our problem, by explaining how costly it could be to ship equipment to a site. This could cost upwards of millions of dollars. This helped us change our solution to also be a cheap kit that archaeologists could add 3D printed parts onto, and bring multiple copies in case one of the broke.

Experts emailed

Dr John McCarthy
Associate Professor Jonathan Benjamin
Chelsea Wiseman
Michael O'Leary (UWA)
Jerem Leach
Ingrid Ward
Hiro Yoshida

Institutions emailed

Australasian Institute for Maritime Archaeology

Minderoo UWA Deep sea Research Centre
Western Australian

After Regionals

Maritime archaeologists (UWA):

5. Johnathan Benjamin (already emailed but follow up can be good)
6. Dr Michael O' Leary
7. Minderoo-UWA deep sea research center

Western Australian Museum – Maritime Archaeology dept

- Handles underwater artefacts and wreck recovery
- Email general archaeology staff + conservation staff for feedback on fragility issues

Australasian Institute for Maritime Archaeology

- National body for underwater archaeology
- They LOVE student innovation
- Ask about problems they face with current ROV tools

- □ contact with leadership
- □ contact through the educational pathway
- □ contact with a field professional

Australian National Maritime Museum

- Runs maritime archaeology projects and internships
- Good for asking about object fragility + real ROV field constraints

Underwater Robotics/ROV industry (manipulator arm relevance):

Fugro Australia

- Major offshore ROV operator in Perth
- Their engineers run titan arms almost daily
- Ask about failure modes, pressure issues and real usability

Woodside Energy – Robotis/ROV Team

- Uses ROVs for pipeline inspection.
- Ask about the limits of two finger grippers and collision concerns

IMCA – International Marine Contractors Association

- Industry Guidelines for manipulators
- They can comment on safety or operational problems with current grippers

Schilling Robotics/TechnipFMC (Titan Arm Makers)

- The company behind the titan 4
- Ask about how archaeologists could adapt industrial arms, and whether pressure sensing is realistic

Engineering + Materials Experts (Innovation viability)

UWA Engineering – Mechanical and Mechatronics

- Ask for:
  - Material choices underwater
  - Real world durability
  - Pressure sensor testing underwater
  - Actuators and joint reliability
- Useful contacts:
  - Mechanical Engineering Dept
  - Oceans Graduate School
  - Mechatronics Research Group

Curtin University – Underwater Sensing and Robotics Lab

- They work on autonomous underwater robot, sensors, and novel underwater tools.

CSIRO Oceans and Atmosphere

- Australia's biggest marine research group
- Ask about:
  - Fine manipulation underwater
  - Environmental sensitivity
  - Harsh-operating environment constraints

Marine Conservation + Soft-Handling Specialists (Pressure Control Relevance)

AIMS – Australian Institute of Marine Science

- They handle fragile corals and living samples
- Ask about:
  - Pressure thresholds for soft materials
  - Risk of crushing when sampling organisms
  - How feedback sensors could help

NOAA Ocean Exploration (US)

- They operate ROVs like Deep Discoverer.
- Open to student questions
- Perfect for pressure, touch sensitivity, and handling fragile organisms

Underwater Robotics Startups/Research Platforms

OpenROV/Sofar Ocean

- Small, approachable companies focused on accessible underwater robotics.
- Great for feedback on:
  - Mechanical Grip Design
  - Sensor Integration
  - Low-cost pressure sensing

MBARI – Monterey Bay Aquarium research institute

- World leader in underwater robotics research
- Email engineers or robotics researchers.

Emails regarding our Problem

Thanks for writing. I'm a maritime archaeologist here at the museum.

- Any issues you have experienced with ROV manipulator arms, and more specifically collecting artefacts underwater
  - We have only used ROVs for image capture, and haven't used one with a manipulator arm
- How these issues affected your archaeological operations
  - Many artefacts are incredibly delicate and often need to be excavated (sediment removed around them).
  - Bottles and pottery can also be full of sediment, so they can be very heavy - which is a challenge for some robotic actuators
  - Many WA sites are in shallow waters, and where waves break - so robots could be used on deeper sites only, or would have to be able to controlled in the waves.

Cheers,

Patrick Morrison he/him
Assistant Curator Maritime Heritage

Thanks for reaching out. Yes I have used ROV's to collect stone artefacts from the sea floor, as well as small geological specimens to better understand the primary source rocks the artefacts originate from.

I have the Chasing 2 ROV and we have used a grabber arm https://www.chasing.com/en/grabber-arm-2.html to collect these specimens. The main challenge in doing this is that you have to position your drone in the right position before closing the grabber claw onto the rock sample but this becomes difficult were there are strong currents which make holding the grabber arm in the right position and angle to the sample challenging.

I have been thinking the better option might be a bucket style sediment sampler to scoop up the rocks rather then try and grab them https://www.chasing.com/en/sediment-sampler.html

Happy to answer any other questions you might have

Cheers

Mick

Thanks for reaching out and tackling a difficult problem the subsea world has had for a long time.
I am not an archaeologist, but I can comment on the challenges of using ROVs for science.

ROVs are great tools but they have some limitations. When we collect small animals, like corals, which are very delicate, we run the risk of crushing the animal and its structure. As sad as it is killing an animal for a specific question, if we crush the structure and cannot use it, then we always have another individual from that species which we can find and use. If this is a delicate artifact, it is rare and unlikely to have a replicate therefore it is very high risk picking up delicate artefacts in case we crush it. It is difficult for ROV pilots to feel how much pressure they are putting on the thing they are collecting. There is some work in the medical industry that provides pressure feedback to operator which provides a sense of how much to push. The manip arm is very strong and can easily crush samples.

ROV also create turbulence when they move which can create a cloud of sediment in silty environments. Skilled pilots are very good at reducing this, but it still a problem.
ROV are also tethered to the main vessel which means we need a lot of cable if we want to work in very deep environments. We also have to drag that tether around which can be difficult and dangerous.
The payload of an ROV isn't huge which means they cannot lift heavy things. Some small artefacts can be collected with the arm, but anything larger would need to be lifted using alternative means.

I hope this gives you some ideas about the difficulties working with ROV at depth.

Good luck.
Todd.

Dr Todd Bond
Deputy Director

Emails regarding our Solution

Sounds like a great project, and very challenging as well!

Do you have any images/plans/drawings so I can see more clearly what your approach is? I'll be better able to provide comments then.

W.r.t control vs.materials. There are different (valid!) schools of thought on this question. I prefer focusing on the materials and using simple, repeatable control. Rely on the shape and material composition of the gripper to do the 'heavy lifting'.

There are a few different approaches you can use. Have you thought about some kind of compliant linkage mechanism? They are light and can be approximated using rigid elements so you can do some modelling without much difficulty. One issue with pressure sensors is they might be affected by the ambient pressure – so e.g. if you dive deeper into the water the pressure goes up and the sensors give higher readings.

Thanks,

David Howard, SMIEEE
Group Leader – Robotic Design and Interaction
ACM Distinguished Speaker
david.howard@csiro.au | 07 3327 4714
QCAT 1 Technology Court Pullenvale 4069 QLD Australia
CSIRO: Australia's National Science Agency

Follow up email

Thanks for taking notice of my work, it's really pleasing to see that you've drawn inspiration from it!

Sounds like you're doing some really cool stuff!
My general advice for marine operations is try to minimise the number of moving parts and fasteners.
Everything corrodes or degrades in the ocean!
Systems like passive soft grippers or under actuated tendon-driven systems are simple but effective solutions for grasping unknown objects!

On the sensor integration: how do you know what force is too high?
If you have access to a 3-DOF force sensor, that would be quite useful as the slip (i.e tangental force) is as important as the grasp (i.e normal) force.
You can setup the controller to close further when slip starts

Do you have a cad model or photo of the gripper I could look at?
I could give more specific advice if I can see what you're working with

Cheers

Josh Pinskier
Senior Research Scientist – Robotic Design
Data61 | CSIRO
josh.pinskier@csiro.au | 1 Technology Court, Pullenvale, QLD 4069
CSIRO Australia's National Science Agency | csiro.au

Congratulation on your initiative. Some thoughts below:

- We always consider the objects first and then if necessary custom build solutions especially important is the crate/ container the item has to be put in for travel from seabed to the surface as it has to also protect the object(s)
- The container should be cushioned and allowed to contain seawater (for protection and so object doesn't dry out)
- The pressure sensors and swivelling options sounds good and should work for most smaller items
- This machine the 'Crabster' was developed by the South Korean Maritime Heritage Unit for deep sea recovery and is a good model also: https://edition.cnn.com/2014/04/01/tech/gallery/giant-six-legged-robot-crab
- Timbers are large and heavy and so would not necessarily be raised by a small-medium size robot, but the robot could attach slings or something perhaps to be raised by an above-water crane

I hope this information is useful to you

Kind regards
Ross

Ross Anderson
Curator
Western Australian Museum

P. 08 9431 8442 **museum.wa.gov.au** **Join us @wamuseum**

Thank you for your email. It is always great to hear about a group of passionate about protecting underwater cultural heritage, and youthful and innovative ideas are what help evolve the archaeological discipline.

Your overall concept sounds great and very useful. The **sponge-like padding on the claws, built-in pressure sensors, and a rotating pad assembly,** will help reduce the destruction of artefacts upon removal.

A few additional considerations:

- Many of the more fragile items can be quite small (i.e. buttons, clothing, ceramics, pewter cutlery etc.). How nimble is the claw? (perhaps you can test your claw on a dry leaf that has been submerged to simulate a fragile piece of waterlogged textile).
- What material types have you considered for the padding? Will fibres get stuck in/to an object? This can have an adverse impact when the claw lets go of the object.
- When archaeologists excavate, we remove millimetre levels of sediment at a time, to ensure we don't lose important information/objects. Does the claw have a mechanism for removing small layers of sediment to fully expose the object before removing it (i.e. can it wave side to side to clear sediment off an object before recovering it)?

Good luck at the competition!

Regards,

Deb

Although we haven't used one, I believe that this is a problem for maritime archaeologists. I recall seeing some examples in the past, but we would certainly like to have some adaptation for our gripper when we buy one. Other useful adaptations would be water jets to clear marine silt and mini-dredges to hoover away the same silt (which reduces visibility less than water jets).

The material we are most likely to recover is generally robust though, ceramics and stone tools. Soft grippers would be most suitable for soft organic material. Such material is often encountered in the Baltic, even Mesolithic oars. Cave environments could also host such material.

I hope that helps,

Kind regards,

John

Dr John K. McCarthy
DECRA Fellow and Senior Lecturer in Maritime Archaeology
Maritime Archaeology Course Coordinator
President, Australasian Institute for Maritime Archaeology
Council member Computer Applications in Archaeology Australasia (CAAA) Chapter
Flinders University, Room 3115 Social Sciences North, Sturt Road, Bedford Park 5042, South Australia

P: +61 8 8201 2163 | M: +61 401 650111 | www.flinders.edu.au

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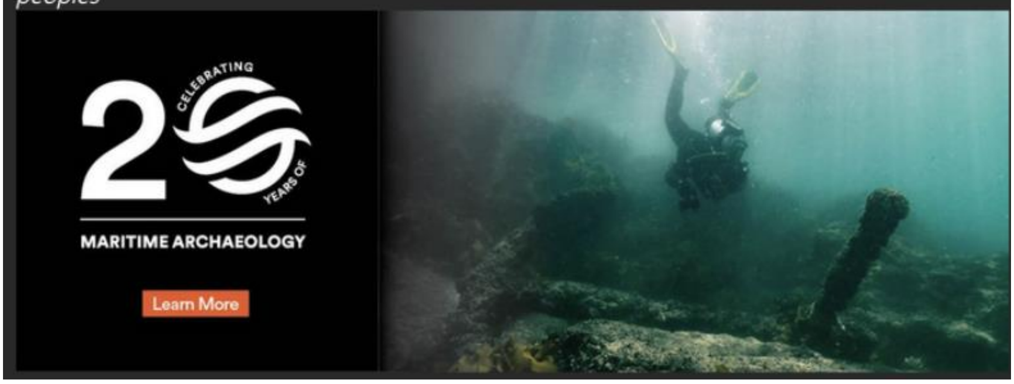

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I hope this information is useful to you

Kind regards
Ross

Ross Anderson
Curator
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Call with Tim MacDonald

We asked Tim MacDonald numerous questions. They concerned mainly about how our arm compared to others, materials that we should use and the prevalence of our problem. These were our notes:

Soft jaw grippers, have 2 floppy bits of rubber and when they close in it just holds it together with a sticky bit of silicone, but there's no force sensor.

Pressure sensor is good, expert said its good, its cheap, its reliable.

Biggest cost and feasibility

says our project is good because its low cost and can be made cheap. main thing driving up cost is the housing for electronics and making it waterproof.

circuit board without oscillation, everything can be put in oil, grape oil, caster oil, transformer oil. Put all the electrical stuff in a box full of oil and as long as the oil isn't conductive you'll end up with a really cheap pressure boundary. If you have a box of air it will have to be thick and strong to withstand the pressure (not good).

Use clear garden hose and put the cables in the clear tube and fill it with oil, seal the ending with whatever.

Says the problem is a prevalent problem in current underwater archaeology. current solutions work and are fine but are all homemade people in the field just trying to show you, same as what we are doing, 3d printed prototype with trial and error.

Says our pressure sensor takes it to the next level

lot of other applications apart from just marine archaeology, we could use it to pick up delicate deep-sea coral, gelatinous animals. Good for sediment sample, to measure the sediment properties, whatever. Try to understand how much force things are needed for different things are useful for science and other fields.

Our thing is good because we are simplifying compared to other related things, good because its cheap and simple. The biggest cost in archaeology is time, need to do so many different steps, so by the time you get there you've probably spent millions of dollars and all of a sudden your suction gripper breaks because it has so many parts and its all waste.
suction grippers can be destructive with all the force they apply, cant pick up gelatinous things.

Our arm increases the reliability, benefits over the suction sampler. Our arm is more so relevant in archaeology because of all the delicate things.

Other benefit on the design is we can put this on any vehicle we want because its simple.

Schmidt oceanographic institute has a cool ROV.

keep with 3d printed because cheap and anyone can buy. Because it's so cheap anyone can buy anywhere, can be manufactured anyway like a kit or something
titanium will have issues, expensive, corrosion

Stick with plastic if mounting ROVs, archaeologist usually put 3d printed parts on their ROV cause they want to pick delicate things.

refine the design, make it look pretty.

cheap 3d printed reproducible and easy to put together

nylon 12 plastic https://en.wikipedia.org/wiki/Nylon_12 with carbon fibre, makes it more rigid, we essentially want any plastic that doesn't absorb water and its properties don't change due to water. Nylon 6 absorbs a lot of water and will degrade around 60-70% over time. PTFE plastic https://en.wikipedia.org/wiki/Polytetrafluoroethylene, Teflon, is also quite good ecpert has used 3d printed things all the way at the bottom of the mariana trench, 3d printed is good.

only other piece of advice, send calendar invite to expert to give them a chance to say no cause theyll be inclined to send another time.