Subsea Kinetics

ROBERT GORDON UNIVERSITY, ABERDEEN, SCOTLAND

Team Members & Roles		
CEO/Pilot	Adrian Przenioslo	Mechanical Engineering
Co-pilot/Software Engineer	Philip Thomson	Electronic & Electrical Engineering
FEO/Mechanical Engineer	Rory Patterson	Mechanical & Offshore
Electrical Engineer	Greg Hanson	Electronic & Electrical Engineering
Research & Development	Alistair Garden	Mechanical & Electrical Engineering
Electrical support	Stewart Pitt	Electronic & Electrical Engineering
Mentors & Associates		
Program coordinator	Graeme Dunbar	
Mechanical Support	Martin Johnstone	
Electrical Support	John Still	
	Steve Allardyce	
Mentor	Mihai Andrian	Electronic & Electrical Engineering

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Abstract

Subsea Kinetics is relatively new company pushing the boundaries in subsea industry. Company specialises and provides services in few different categories:

- ROV exploration
- X-mas trees and pipelines
- Control systems

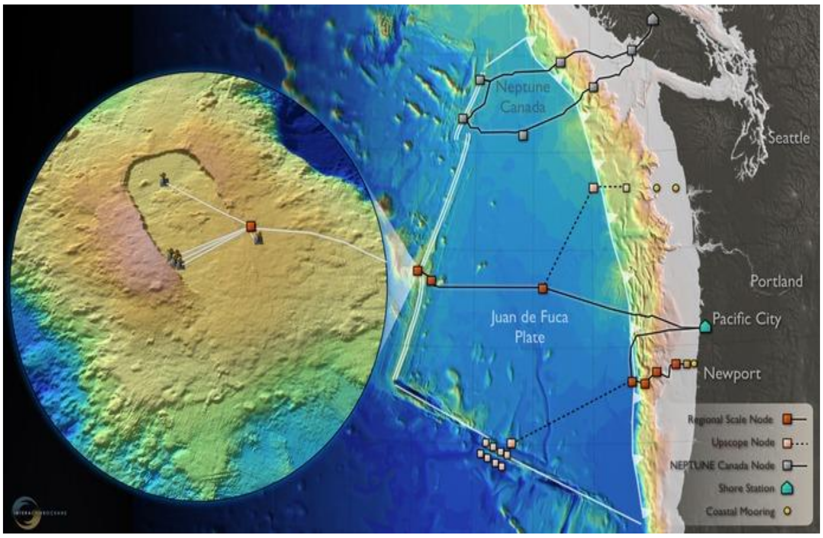
Subsea Kinetics ROV division offers safe and efficient service of operating, surveying and exploring subsea environment. Their ROVs have uniquely designed chassis allowing the operation multiple tools, easy navigation and depends on the operation – advanced sensors and telemetry.

Compact design including vector propulsion system provides ability to operate in confining spaces where sending human divers could be too risky.

1. *Introduction and background*

The earth's oceans are the last part of our planet that we still have very little knowledge about even though it accounts for over 70% of the surface and is a crucial factor to life on this planets continued survival. Any step however small in increasing our pool of knowledge would be beneficial now and in the future monitoring the ever present changes in our planet due to the threats of climate change, changing currents and the threat of extinction for many creatures. The effect of the oceans on human life is also incalculable from basic food stuffs that feed millions of people to the storing of carbon dioxide in algae slowing down the rate of temperature rise.

One of the current plans to combat this lack of knowledge is to put in place underwater observatories which will allow scientists to place sensors and recording devices on the sea bed and leave them to record for a large period of time. This allows the monitoring of a specific location over that period giving data back about factors such as salinity and temperature which would give an indication of the overall 'health' of that area. It could also collect data on sea currents to help sea transport and to help forecast climate events such as El Niño and La Niña that have a direct effect on humans.



The monitoring of vent sites such as at the axial seamount volcano, allows for the continual analysis of the volcanic output of the hydrothermal vents in an area giving an indication of the stability and nature of a tectonic plate that has only been possible in the past when a fault line has crossed an area of land. The studies In this area also give data about how these volcanos create conditions for an Abundance of life in conditions that do not Allow sunlight through the biological and chemical material that is ejected by the vents. Placement of nodes on the Juan de Fuca plate Sourced from:- www.ooi.washington.edu/story/Axial+Seamount

2. *Aims & Objectives*

The main objective of this project is to produce a safe, high quality vehicle capable of performing the tasks set out and to complete the project on time and on budget.

The secondary objective is to apply knowledge gained in class and test ability to work as a team. Right from the start, it was made a mandatory objective that every team member should have fun while working on the project.

3. *Project management*

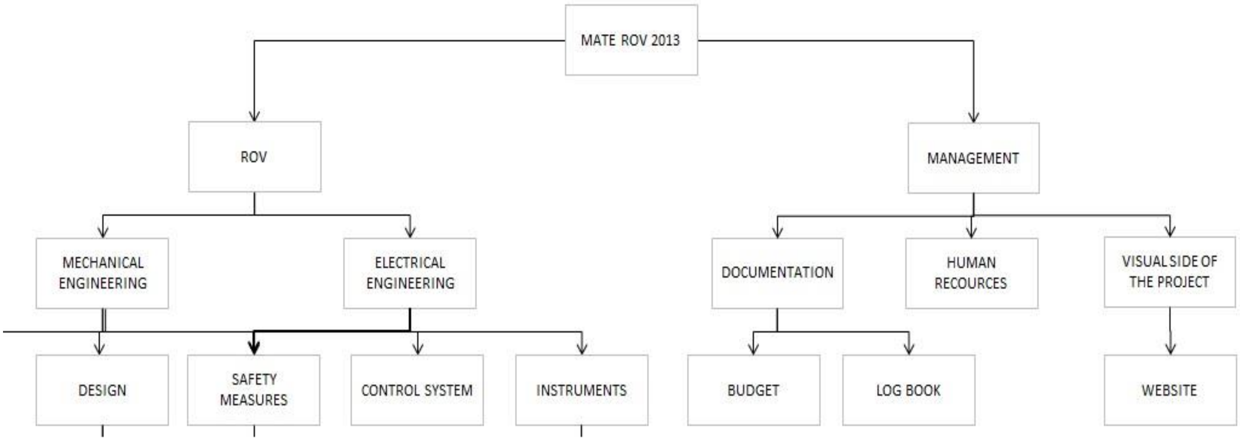
3.1. Team

After previous entry Adrian, Philip and Rory recruited Greg, Stewart and Alistair to join the team for another attempt. Current squad of Subsea Kinetics consists of Robert Gordon University Engineering students from different departments and years.

[Picture 1: Subsea Kinetics – (from top left: Stewart Pitt, Greg Hanson, Rory Patterson, Alistair Garden, Philip Thompson, Adrian Przenioslo]

3.2. Word Breakdown Structure & Gantt chart

Different management tools were applied during the project, such as Work Breakdown Structure and Gantt chart.



[Full Work Breakdown Structure is available in Appendix 1]

Preparation of the Gantt chart was the next stage after work breakdown structure analysis. Project was divided on different phases which were representing milestones in the project:

- *Phase one* – it was starting point of the project, the first two weeks were assigned to the assembly and synchronization of the team. During that time the team had a chance to get familiar with messaging system, e-mail addresses and official forum.
- *Phase two* – basic design. According to the work breakdown structure team leader picked up task and activities that are necessary to complete the project.
- *Phase three* – tests. Once phase two is finished next stage is to test the basic design and in case of any failure allocate time for repairing or redesigning faulty components
- *Phase four* – tools and instruments. Phase four indicates only that project is still open due to fact that work on SK-1 is still in progress. Team is restless in developing and adjusting tools and electronic systems.

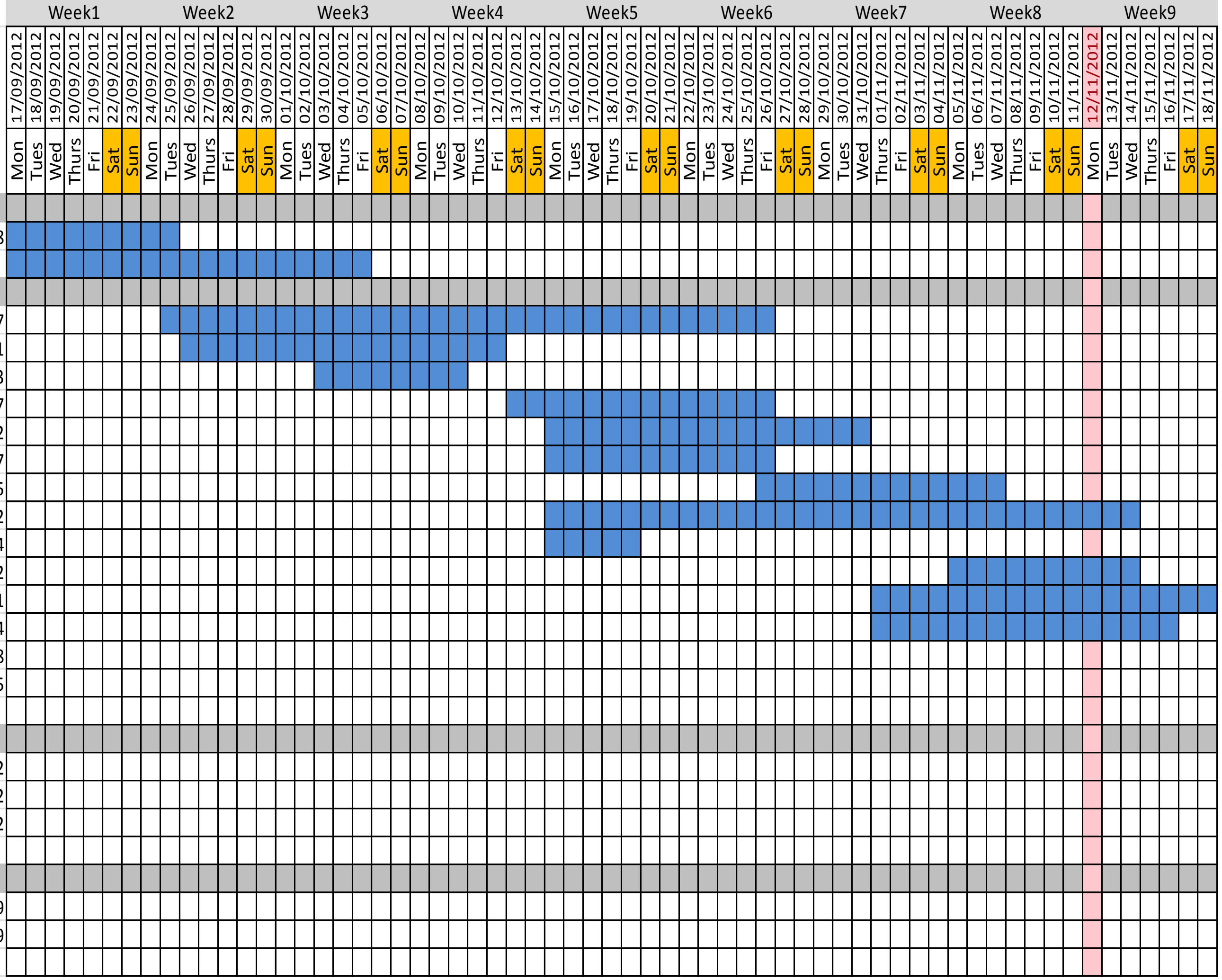
MATE ROV 2013

SUBSEA KINETICS

TODAY'S DATE	12/11/2012	START DATE:	17 September 2012
DURATION:	37 Weeks	END DATE:	01 June 2013

READ THAT: Project finish on PH3 on 14/12/2012. PH4 & 5 starts from 01/02/2013

	Phase Level	Task	Assignment	Start Date	Finish Date	Days Complete	Days Remaining
	1	**PHASE ONE**					
1	1.1	Team assemble and synchronization		17/09/12	25/09/12	56	-48
2	1.2	E-main accounts, website & forum		17/09/12	05/10/12		
	2.0	**PHASE TWO - BASIC DESIGN**					
1	2.1	Mechanical design	Mech	25/09/12	26/10/12	48	-17
2	2.2	Motor Controller & power board v1 test	Electr	26/09/12	12/10/12	47	-31
3	2.3	Control System basics working	Electr	03/10/12	10/10/12	40	-33
4	2.4	Motor controller & power board redesign	Electr	13/10/12	26/10/12	30	-17
5	2.5	Motherboards design	Electr	15/10/12	31/10/12	28	-12
6	2.6	Control box & Fuse box design	Electr	15/10/12	26/10/12	28	-17
7	2.7	Control box & Fuse box manufacture	Mech	26/10/12	07/11/12	17	-5
8	2.8	Control system code complete	Electr	15/10/12	14/11/12	28	2
9	2.9	Pressure Vessels design	Mech	15/10/12	19/10/12	28	-24
10	2.10	Pressure Vessels manufacture	Mech	05/11/12	14/11/12	7	2
11	2.11	Camera system design	Electr	01/11/12	23/11/12	11	11
12	2.12	Camera housing design	Mech	01/11/12	16/11/12	11	4
13	2.13	Camera housing manufacture	Mech	19/11/12	30/11/12	-7	18
14	2.14	Waterproofing	Mech	30/11/12	07/12/12	-18	25
15	2.15						
	3.0	**PHASE THREE - BASIC DESIGN TEST**					
1	3.1	Waterproofing system test	All	10/12/12	14/12/12	-28	32
2	3.2	Vector thrust test	All	10/12/12	14/12/12	-28	32
3	3.3	Camera system test	All	10/12/12	14/12/12	-28	32
4	3.4						
	4.0	**PHASE FOUR - TOOLS & INSTRUMENTS**					
1	4.1	Design & manufacture starts after exam session	Office	01/02/13	01/03/13	-81	109
2	4.2	Mission Planning and executing	All	01/02/13	01/03/13	-81	109



[Figure 2]

3.3. Expenses

No.	Part	Unit Price	No. of parts	Total Price	Donation	Expenditures
	Expense Sheet					
1	PVCu Pipe Class E 15 Bar 6m 1/2”	£3.82	2	£7.64		X
2	PVCu Pipe Class E 15 Bar 6m 1/2”	£3.82	1	£3.82	X	
3	PVCu Elbow 90 Plain 1/2'	£0.71	10	£7.10		X
4	PVCu Elbow 90 Plain 1/2'	£0.71	15	£10.65	X	
5	PVCu Elbow 45 Plain 1/2'	£1.33	10	£13.30		X
6	PVCu Elbow 45 Plain 1/2'	£1.33	10	£13.30	X	
7	Rubber lined pipe clamp with one fixing 100mm x M1	£1.49	4	£5.96		X
8	MOSFET N-Channel 100V 9.7A TO220AB	£0.73	5	£3.65	X	
9	MOSFET N-Channel 60V 17A TO220AB	£1.33	5	£6.65	X	
10	Relay SPDT PCB sealed,16A 48Vdc	£3.22	5	£16.10		X
11	Optocoupler Transistor O/P 1-CH	£0.35	1	£0.35	X	
12	Economy printer cable,5m	£3.68	1	£3.68		X
13	Heat sink compound,20 ml tube	£3.75	1	£3.75	X	
14	Clear acrylic pipe with 100mm OD and 94mm id	£15.75	1	£15.75		X
15	Arduino mini	£9.00	5	£45.00		X
16	IP65 Grey Lid Enclosure, 201x163x98mm	£9.29	1	£9.29		X
17	IP65 enclosure w/grey lid,160x85x80mm	£17.88	1	£17.88		X
18	Grn/yellow unshielded RJ45 LED skt,1.5A	£1.59	4	£6.36		X
19	MOSFET N-Channel 60V 50A TO220AB	£1.51	15	£22.65		X
20	SIMPLE SWITCHER 3A Reg LM2576HVT-ADJ/LF3	£4.50	5	£22.50		X
21	Color Board Camera with OSD Menu DNR	£28.07	4	£112.28		X
22	Power Inductor 100uH 2A	£2.19	5	£10.93		X
23	Bilge Pumps	£30.34	10	£303.40	X	
24	3axis joystick	£72.97	1	£72.97	X	
25	Propellers	£2.06	10	£20.60	X	
26	Cable glands	£3.50	15	£52.50	X	
27	Voltage regultors	£4.50	4	£18.00	X	
28	Slide potentiometers	£1.20	2	£2.40	X	
29	Rotary switch	£1.20	2	£2.40	X	
30	LEDs	£3.75	1	£3.75	X	
31	CAT6a FTP 10GB RJ45 Patch Cord 20m	£31.30	1	£31.30		X
32	2way connector plug IP68	£12.58	1	£12.58	X	
33	3 way connector coupler socket IP68	£10.95	1	£10.95	X	
34	8 way connector socket IP68	£3.17	1	£3.17	X	
35	8 way connector coupler plug IP68	£3.06	1	£3.06	X	
36	5A solder pin contact, 22-26 AWG	£4.28	1	£4.28		X
37	5A solder socket contact, 22-26 AWG	£6.76	1	£6.76		X
38	Bulgin 900 buccaneer gland pack	£1.32	1	£1.32		X
39	2.5mm 3 core flexible cable (20m)	£33.35	1	£33.35	X	
			TOTAL:	**£941.38**	£581.30	£360.08
			Conversion to US Dollars (22nd May 2013)			
			1	USDollar=	0.66	GBP
			TOTAL:	**$1,426.33**	$880.76	$545.57

4. *Design rationale*

4.1. Safety considerations

Safety was the most important factor at all times during the design and testing of the vehicle.

All team members had been through mandatory safety training as part of first year module “Professional Skills”.

While working in the laboratory a number of safety procedures were followed

- All mains electrical equipment is PAT tested.
- No electrical sources of any kind allowed near the testing tank.
- Testing power supply limited to 5A.
- Lone working in the laboratory prohibited.
- All mechanical tools in good condition and inspected before use.
- Risk assessment and risk reduction procedures mounted on the wall in the laboratory.
- Appropriate personal protective equipment was provided and used whenever necessary.
- Any new components must be initially tested remotely with a shield between the components and personnel.

The vehicle itself is fitted with a number of safety features.

- Over current protection in the form of a 40A fuse, mounted in it’s own container, close to the supply.
- All propeller blades are shrouded and contained within the footprint of the ROV. No moving part of the vehicle protrudes outside of the main framework. In addition propeller blades have their own protection
- The vehicle is made using round plastic materials with no sharp edges.

While operating the vehicle the team has developed a strategy for safe operation.

<u>In addition to the safety procedures set out by the host venue and the MATE institute.</u>

- The tether operator is the only member of the team constantly at poolside. This person should be a strong swimmer and not wearing shoes or heavy excess clothing. The tether operator should ensure excess tether is kept tidy where it can not be a trip hazard.
- Other personnel should be well clear of the pool.
- Vehicle is not powered up until person carrying the vehicle to the poolside signals the pilot to power up. The power up signal should only be given when all personnel on the surface are clear of the vehicle.

4.2. Structural frame

The SK-1 frame consist of two pressure vessels located on top of the frame and secured by pipe clamps, mounts and attachments for the tools, cameras and thrusters.

The final design was selected for the stable support of the ROV in the water by using pressure vessels as a buoyancy material and therefore saving space in the lower section for tooling. Due to transportation limits the maximum dimensions of the whole ROV are 450x400x350mm however for increasing the payload area a dismountable skid was attached therefore total height of the SK-1 is 430mm. Frame allowed room for eight thrusters - each of them enclosed within the frame for safety reasons and to avoid repositioning.

The main material used for SK-1 chassis is PVC pipes, elbows and tees. This material was chosen over alternatives since it provides sufficient strength, it is easy to cut, assemble and also is light and cheap.

After precise measurement and cut frame was assembled by simply slotting it together and securing joints with self-tapping screws. Hollow structure of the frame allowed to run most of the cabling components through it and therefore providing security. 2.5mm holes were systematically drilled through each pipe and therefore allowing frame to be flooded and drained much faster.

4.3. Buoyancy & Stability

It was extremely important to provide stable operation of the ROV therefore Buoyancy was carefully calculated using the following formula:

$$Buoyant\ Force\ (B) = \rho \times g \times V$$

Where V is the displaced volume calculated from:

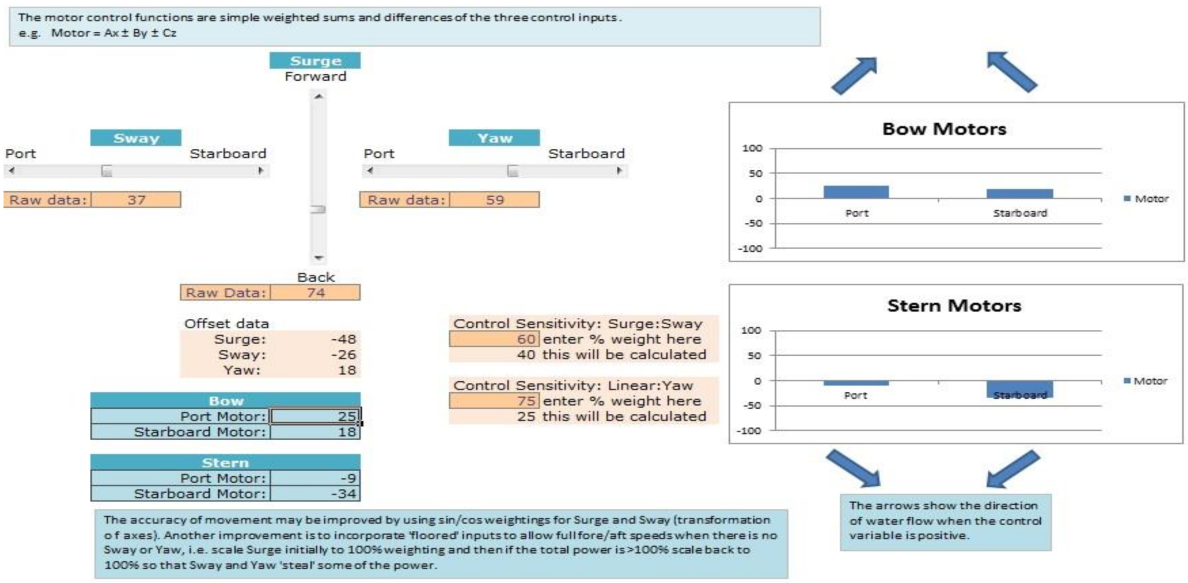
$$V = \pi r^2 L$$

Two pressure vessels provided sufficient buoyancy and stability of the ROV. However due to complex shape of the ROV, Centre of Gravity (CoG) and Centre of Buoyancy (CoB) was achieved experimentally with aid of trimmed led for balancing.

4.4. Propulsion system

Propulsion system of SK-1 ROV consists of 8 thrusters, made form modified 24v Bilge pumps. The pump casings were removed and original propeller replaced with hobby speed boat propellers manufactured by Graupner Co. The advantage of using bilge pump was that provides waterproof motor with suitable torque.
The layout of the propulsion system provides full manoeuvrability due to using what is called vector propulsion system – four thrusters were placed horizontally in 45deg angle with the frame. Four thrusters placed vertically and in co-axial layout allowed SK-1 dive and surface very quickly.

The mixing formula was based on excel spreadsheet as seen below.



4.5. Cameras housing

Camera housing was designed in SolidWORKS and machined on site. The advantage of this design is that it consists of 3 main parts: main body, cable gland and front Perspex with o-ring. Securing with 8 screws limited the possibility of leaking.

4.6. Payload tools

Payload tools are still work in progress. So far SK-1 is equipped with set of metal hooks placed at different angles, two separately controlled motors with attachments for grabbing or carrying tools and crates

5. Electronics

5.1. Control Box

The control boxes were designed with several key points in mind.

- The control boards should be completely detachable from all inputs, outputs and internal controls.
- The pilot should play a key role in deciding the layout of the controls, to ensure controls are laid out in a way the pilot finds natural and ergonomic.
- The control boards should feature as few components as possible to minimise current draw from the ROV.

With these key points in mind the control boards were designed to use Cat5 connections to allow for rapid and reliable connection of data cables.

The Arduino boards are connected using pin headers meaning either Arduino can be removed and replaced very quickly. Both Arduino boards in the control box run an identical program. In the event of a failure a spare Arduino with the program already loaded can be installed very quickly with only minimal downtime.

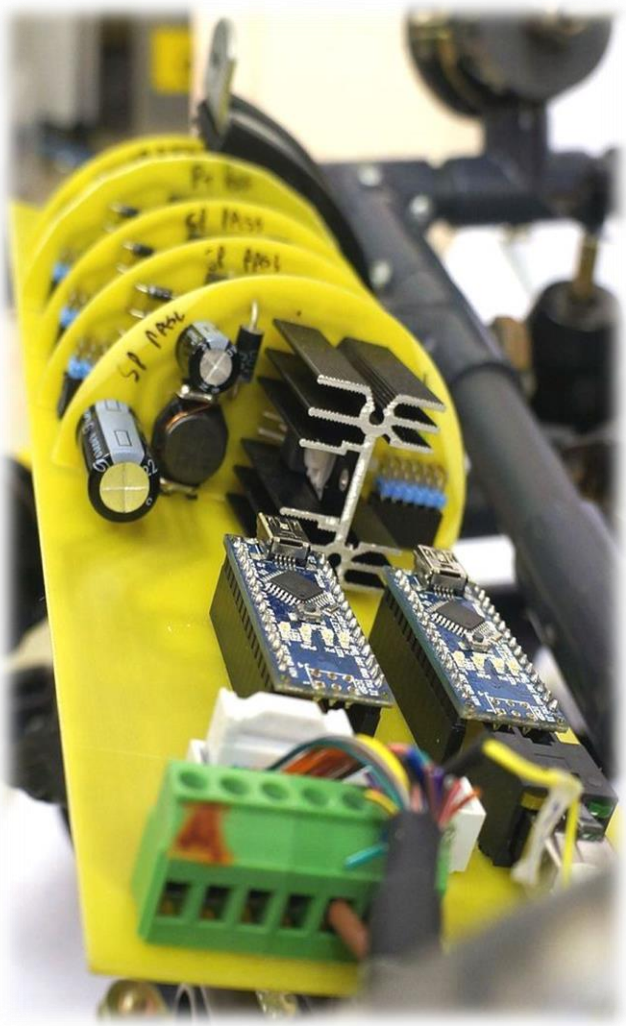
The controls are completely detachable from the control board allowing the control box lid to be completely removed without vulnerable cables being forced to remain connected.

The actual controls are mounted as close to the centre of the control box as possible. This leaves the outer edges free for the pilot to rest their hands on the control box, giving a more ergonomically friendly design. The co-pilot control box follows the same design idea.

5.2. On-board control

5.2.1. Motherboards

The motherboards are a unique design to reduce the clutter of wiring and reduce mistakes that can be caused by incorrect wiring.



Inspired by computer motherboards, by using a single large PCB sheet, all tracks route connections to their destinations. Additional control boards and microcontrollers are directly connected to external cables by way of the tracked motherboard.
This design although expensive and harder to design is error free and very space saving, neat and more reliable.
All connectors are rated suitably, as well as the correct thickness of tracks on the board to safely handle the current required by that particular load.

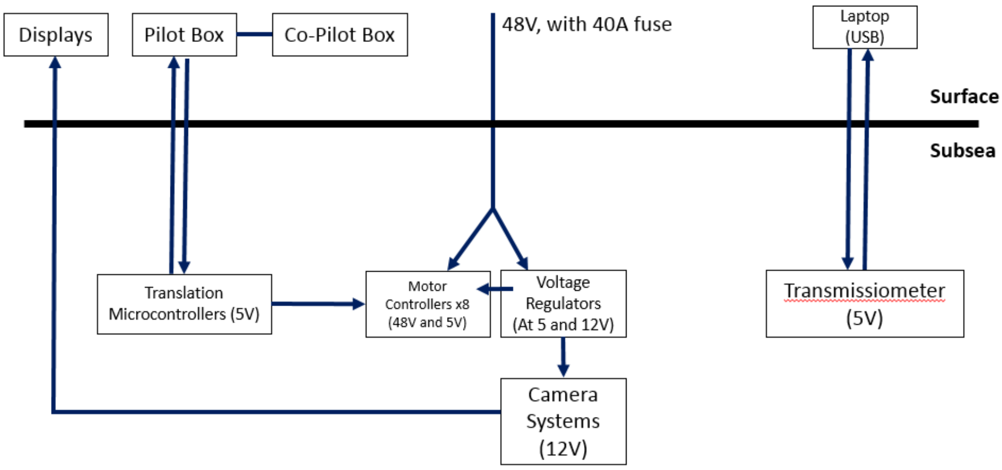
5.2.2. Control system

From the tether, a serial communication signal from the surface is received by the onboard Arduino and translated back into specific commands for each function on the ROV. All motor controller signals use this method. These controllers do not perform any calculations, but act as a link between the main controllers on the surface and the destination motor.
The main advantage of this is once the serial protocol and the translation program is written for the subsurface controllers they don't need any re-programming or removal from the ROV. Any changes or modifications required can be made on the surface where it is easier to make them. The on board micro controllers run an identical program. In the event of a failure, a replacement Arduino can be fitted with only a small amount of downtime.

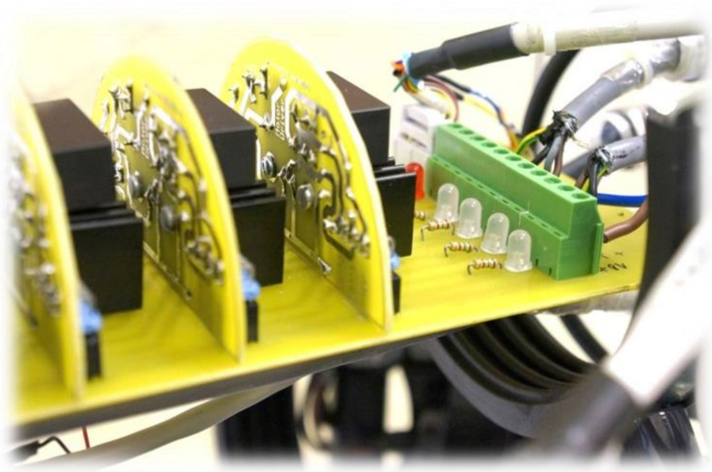
5.2.3. Serial Protocol

Our serial system sends packets to and from the ROV, not requiring any clock signal only two wires are required, a Transmit and Receive. The packets are sent in an order that both sides can understand and translate as required as well as bits for start/stop and to ensure safety if any problem occurs communication ceases safely.

5.2.4. Electrical system flow chart



5.2.5. Power Distribution and Motor Control Boards



All on-board electronics were designed to be completely modular. In the event of one board failing the entire board can quickly be replaced with another.

All motor control boards are identical, minimising the number of spare parts needed while the vehicle is on deployment. Similarly, if an essential board fails it can be replaced with a non-essential board to minimise downtime.

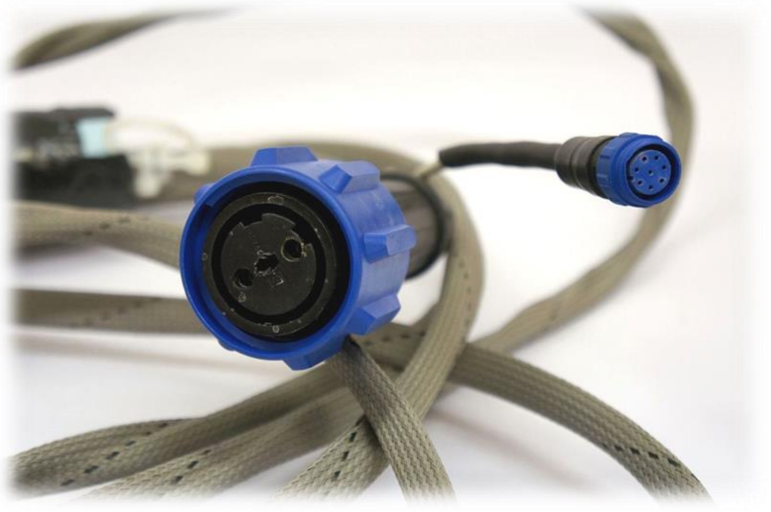
Two voltage regulation boards are used to drop the supply voltage down to values required for the various systems of the ROV. Five volts for the direction control relays and Arduinos. Twelve volts for the cameras.

The 12V board is used for supplying the camera systems of the ROV.

Each motor control board receives 4 inputs; 48V, 5V, Pulse Width Modulation (PWM) and Directional Control Input (DIR). Each board has one output, directly to a motor.

The PWM signal controls the voltage output of the motor control board and the direction signal controls if the relay is high or low. With the relay high, the polarity of the output motors is reversed.

5.3. Tether



Three tethers are used for signals to prevent interference. The main 48V power tether provides suitable capacity for 40A being drawn safely. The control tether used for the serial communication between the Surface Control Unit and the underwater vehicle control system. Within a standard Cat5 Ethernet cable, two twisted pair cables carry the Transmit/Receive signals for movement and tooling control. Another tether is then used for camera's, with individually shielded twisted pairs to reduce interference on the camera feeds and ensure the picture quality is good for the pilot and co-pilot. All three tether cables are then kept within a signal outer sheath to ensure that these cables are easy to manage and deploy.

5.4. Sensors & Telemetry

To measure the opacity of the water the developed optical transmissometer is exceedingly simple. It features a light source on one side with a potential divider on the other.

Each part of the transmissometer is contained in its own waterproof case which is then secured to the central holder. This holder shields as much outside light as possible from the sensor and keeps the light source and sensor at a pre-determined distance to allow for easier calibration. The sensor is made up of a potential divider with a light dependant resistor.

The transmissometer is powered from a tether connected to a surface Arduino. This surface Arduino records and graphs the opacity measurement at a rate of 2Hz.

5.5. Camera system

The camera system was designed to be simple.

Studying previous ROV's it was noted that a key problem with multiple cameras is ghosting of images. In order to solve this problem the decision was made to have no common ground on the cameras and to feed every signal and ground into the tether.

The tether is made up of a Cat6 Ethernet cable. Cat6 was used to eliminate interference between signals and the main power tether as much as possible.

All camera control is done at the surface by way of two quad way di pole rotary switches. The pilot and co-pilot can each have their own video feeds which can be controlled independently. This removes the need for the pilot to share a single video feed to allow them to concentrate on their own tasks.

Each of the control switches is attached to the control box by way of a ten core ribbon cable. Easily detachable from the main board the switches can have spares built and ready to replace with no soldering or electrical work on site.

The decision was made to use a SONY Super HAD' 'as it provides integrated regulator, menu system and runs on 12v – minimising the need for any additional regulators to be implemented. Camera also provides basic On Screen Display and can be tuned for underwater conditions.

6. *Troubleshooting & Challenges*

The biggest challenge for Subsea Kinetics was to make sure that pressure vessels containing the electric circuits remains dry after submersion. Due to large number of cable glands probability of leakage increased and several designs of pressure vessels were considered. After manufacture pressure vessels were sealed and submerged to 2m depth and left over night. After proper installation leakage was limited and by redesigning pressure vessels and fixing all errors the pressure vessels were considered sealed.

Designing voltage regulators and H-bridges were the most time consuming activity. The main problem was occurred due to limited space in the pressure vessel and large number of H-bridge printed circuit boards. The lesson learn from it is to design mechanical system simultaneously with electrical system.

7. *Future improvement*

A drastic increase in power of motors combined with a "gear" system on the control box. „Tortoise" would make the controls much less responsive and allow for fine positioning control. „Hare" would make the controls much more responsive and give the ROV full power to travel from one place to another very quickly.

Further investigation, development and optimisation of tooling.

8. *Lessons learned & gained experience*

This section consists of team members personal statements:

"Mechanical and subsea engineering is my passion therefore Subsea Kinetics was one of the best projects I was involved in during my university time mainly because it combined both of those disciples but also because it allowed me to directly apply learned knowledge gained during the classes. Since I was involved in the competition last year, this time I wanted to focus on the project management aspect. Leading a team of six people was quite challenging. It proved that not only the technical part is important when delivering the product but also how team members see each other. Managing and solving problems between two members of Subsea Kinetics team exposed me to situations where I had to objectively approach situation with both sides presented by friends. Some decisions made a strong impact on the team but since we are still together proves that we have the personal skills to work through problems. It was a great pleasure to work with my team and I hope we will be able to repeat that in the future."

- Adrian Przenioslo

"This project has been very challenging and enjoying for me personally, with a number of technical challenges in the design then in implementation it has required a great amount of problem solving to get ideas and concepts into practice.

Organisation has been key in this project, to ensure delivery on time and on budget our project manager has done a very good job of keeping the team on track throughout the project.

I have learnt a lot from this project, and being able to apply learnt theory into practice then faced and tried to overcome problems has taught me about the real life problems that you have to take into account when designing.

I have thoroughly enjoyed this project and very pleased with the final product that has been developed by our team."

- Philip Thompson

“My experience with the Subsea Kinetics team has been incredibly rewarding. As a second year student joining an existing team I was excited and keen to prove myself to the more experienced team mates who participated the previous year’s competition. Working with a team of experienced people gave me the direction and confidence needed to design and build the components I was asked to build, while at the same time keeping up with my university studies. The biggest lesson I will take away from the experience is more about the product development cycle than the engineering. How team discussions about how to solve problems develop and evolve through knowledge and experimentation to give final products. “

- Greg Hanson

“*This project has been a great experience in my university career, the ability to apply the knowledge learned in lectures to an actual project has been a rather fun endeavour. It has also given me insight to vast potential of work in the line of discipline I am studying. The team has been a privilege to work with, and given that I joined the project in the start of my second year of the course, they were very helpful in aiding me with concepts I did not understand or had yet to learn.*

One reject was greatly underestimating the level of work involved with this project. I wish I knew more on how much effort was required at the start, but this is my first project and I will learn for this mistake for future projects.”

- Stewart Pitt

“Taking part in the MATE ROV competition has given me a unique chance to participate in a very enjoyable but challenging project. It provided a useful insight into the planning, development and organisation that are required for a successful project to reach completion. Participating has helped me develop my team working, time management and technical skills that I can put to use in my future career. Working as a team member has allowed me to combine my ideas with others from different specialities. My time management has improved combining the project with my university work. The project has provided me with a chance to develop and improve skills in using design software and how to move between theoretical and practical solutions. I have enjoyed the challenge of overcoming problems that developed throughout the design and build sections of the task and the design process for the parts of the ROV that I was involved in.”

- Alistair Garden

9. *Acknowledgements*

First and foremost, we would like to thank to MATE for running and organising this event. They gave us great opportunity to learn about ROVs and subsea engineering in general. We also would like to thank to our sponsors for providing funds for us to compete. Besides, we would like to thank the authority of Robert Gordon University (RGU) for providing us with a good environment and facilities to complete this project. Also, we would like to take this opportunity to thank the academic staff, Graeme Dunbar, John Still, Steve Allardyce and Alan Mclean without their advice and assistance would mean that we would have got nowhere with this project. Thanks also to Mihai Andrain who has mentored our group.

Finally, we would like to thank to Martin Johnstone for manufacturing detailed components with greatest precision, advice and patience.

Without the help of the aforementioned, we would have faced many more difficulties while working on this project.

Thank you.

10. *Appendices*

Fully assembled SK-1

Eagle CAD drawings