Team Inspiration 2019 RoboSub Journal

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***Abstract*— Team Inspiration, working out of San Diego, California consists of 14 middle and high school students. Given that we did not have as much experience, knowledge and time as other teams, we learned from professionals to organize effectively, integrate existing technologies and be solution oriented. The team is organized into six sub-teams to maximize effectiveness: systems engineering integration and test, electrical, mechanical, payload, software, and business. We used parallel prototyping and modular testing to shorten development time. We strategized to ensure that we explored all possible ways to meet our requirements, then we developed our solutions. The result is a functional autonomous underwater vehicle in less than 4 months.**

***Keywords*— Autonomous Underwater Vehicle, Computer Vision, Parallel Prototyping, BlueROV2**

I. Competition Strategy

Team Inspiration took a systems approach to RoboSub, and we started by learning all the basics of underwater robotics surveying past team's lessons learned and publications. As a team, we decided to focus on learning autonomous, as it is the brain of the robot. We leveraged BlueROV2 as our baseline to jump-start the team learning [1]. We then developed a reliable, modular, simple, and sturdy extruded aluminum frame as the base of our AUV, named Orange, to allow for the addition of payloads. We enhanced the BlueROV2 processing platform by switching to the Jetson Nano. The Jetson includes an embedded Maxwell GPU which allowed for faster image processing (compared to the Raspberry Pi). Our goals for the season are to complete the gate and buoy missions within four and a half months of work, with the stretch goal of additional missions such as slay vampires and surface in an area. These missions require a minimum of 4 axes of movement, computer vision, and hydrophone localization. Our vehicle implements the following sensors: Inertial Measurement Unit (IMU), depth sensor, sonar, leak sensors, cameras, and hydrophones. We utilized these sensors to help keep our AUV aware of its environment. We had three testing platforms at all times: the test bench, BlueROV2 and Orange. Our sub-teams worked in parallel to develop the custom sub and attachments while our programming sub-team developed their code through testing on our BlueROV2, benchtop test setup, and images online. This testing allowed us to ensure the reliability of our AUV by debugging and simplifying the code before we put it in the water. We also balanced learning and being competitive. We chose tasks that have a high point value and that are different from each other so we can maximize the time we have to learn.

II. Vehicle Design (Novel Aspects)

A. Mechanical

Throughout the robot, we used a combination of 3D printed parts with the stock 80/20 parts for a balance of stability and versatility.

Our initial objectives for the sub are:

- Strength
- Protection of thrusters
- Modularity

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From these initial requirements we came up with a box design to enclose all the thrusters and had a lot of redundancy for strength (figure 1).

We then transitioned our AUV to a lighter configuration (figure 2). We added legs onto the AUV so we could easily work on the AUV when out of the water and ensured that the enclosure would be elevated off the ground.

Figure 1: Box structure of the sub. Motors are not across the same plane.

Figure 2: 80/20 bars are stacked to allow for easy addition of T-nuts into the frame with hardpoint for lifting.

It was essential to design a reliable and lasting electronics enclosure which would not break. Because of this, factors such as overheating and preventing too much noise in the electronics was imperative. For our electronics enclosure, we expanded the BlueROV2 electronics board to fit into the 6" enclosure (figure 3). We also based our 2 end plates that hold the electronics board in place off of the BlueROV2 plate (figure 3). These end plates are fastened to the flange of the end cap where the penetrators are so that the electronics board can be pulled out easily. The way that these plates hold the electronics board together is through an m3 threaded rod that connects the end caps.

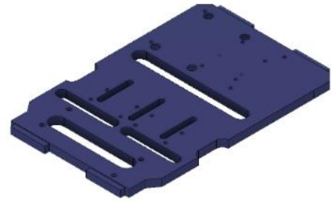


Figure 3: The electronics board. The prongs at the top and bottom integrate with the slits in the end caps.

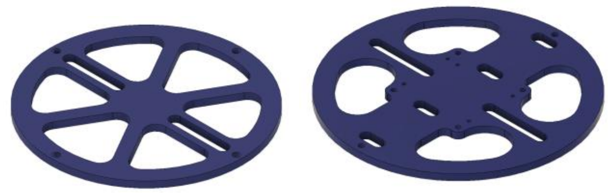


Figure 4: The end caps for our 6" enclosure. From left to right: bottom end cap, top end cap that can hold a camera

B. *Electrical*

The electrical sub-team focused mainly on power distribution and the integration of extra payloads (such as additional cameras, hydrophones, sonar, etc.) within our AUV's electronics system. The sub-team also worked closely with the mechanical sub-team to ensure proper cable routing, minimize signal noise interference and maximize heat dissipation. Additionally, the electronics sub-team was responsible for creating a power budget to ensure that an adequate amount of power was given to all of the moving components.

Analog to Digital Converter (ADC) is used for the hydrophone integration to convert analog to digital in order for the computer to process the signal [2].

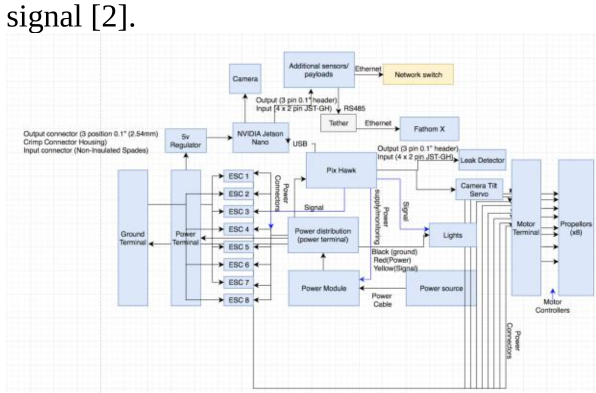


Figure 5: The electronics layout of our AUV

C. Payload

Our AUV will be equipped with 2 hydrophones, 2 cameras, 2 sonars, 1 gripper and 1 torpedo shooter. The 2 hydrophones are used for locating the pinger. The front camera is set up with gimballing and has the capability to look forward and downward. The bottom camera is a failsafe for downward looking only to minimize the gimballing needed for the front camera. Images captured by the cameras will be processed for object detection to aid navigation. To simplify image processing, the image will be analyzed as still frame vs motion analysis. The sonars are used for distance sensing and failsafe for image processing. The failsafe function is activated should the camera fail to detect an object. The hydrophones are used for the surface in an area mission and for our program we are using the Bat Pi [3].

Additional payloads we focused on were the torpedoes and their propulsion. By researching and contacting a Model RC Submarine enthusiast, Bob Martin, we were able to design and create a Water-Jet Propelled Torpedo.

D. Software

<u>Platform</u>

Our vehicle's main (control) computer is an NVIDIA Jetson Nano. Due to its high graphical processing capabilities, one of its primary purposes is to process the images captured by the two cameras mounted on the vehicle. The Nano also sends, receives, and processes the data and messages that come from and go to the Pixhawk, a low-level hardware controller with an integrated IMU. Our computer's software architecture has a vision module and a navigational module at the highest level. The modules are hosted on the computer and receive data from the Pixhawk and the cameras. The Pixhawk's firmware manages the hardware devices and sensors that are attached to it by responding to commands sent by the navigational and vision modules (figure 6).

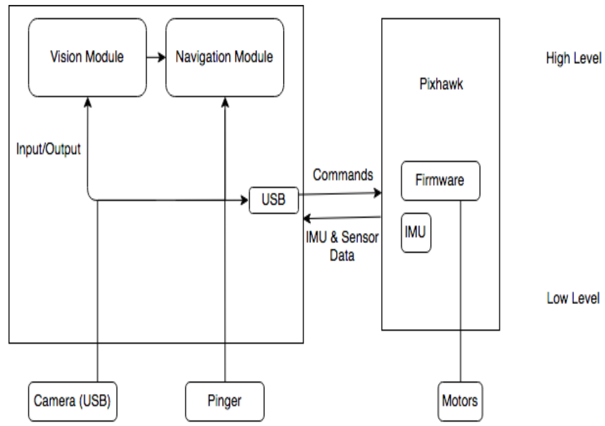


Figure 6: Visual representation of our software architecture.

<u>Communication</u>

MAVLink is the protocol Team Inspiration uses to communicate between the control computer (Jetson) and the Pixhawk. With just 14 bytes of overhead, MAVLink is efficient, extensible, very reliable, and works well even in high-noise and high latency scenarios. To send commands, we utilize a Python-based implementation of MAVLink called PyMavlink. We have chosen to use Python because:

- Python is an interpreted language, which makes testing easier.
- Python is a scripting language, which allows us to focus on the language and syntax.
- MAVLink has a lot of support for Python libraries.

Other aspects of our communication system are:

- Every function across our entire system uses the same reference to the connection to the Pixhawk ("master" object) connection for the sake of simplicity and prevent additional complications.
- The Pixhawk is the device that sends commands to individual motors and sensors on the AUV.

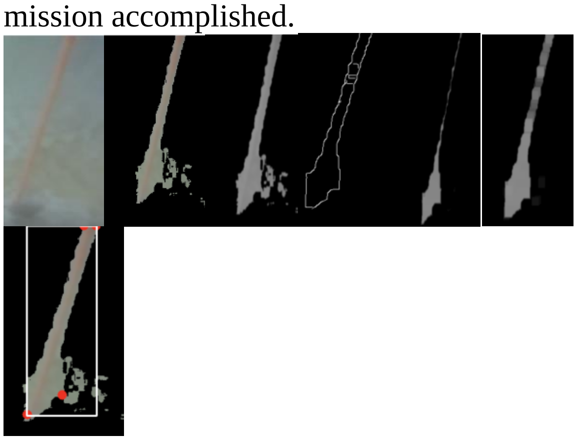
<u>Navigation and Propulsion</u>

Our navigation system entails four drive modes: time, IMU, computer vision, and acoustic. The IMU mode of navigation is primarily used for rotational movements, seldom for translation. The computer vision mode of navigation utilizes input from both the front and bottom facing cameras.

The vehicle will move primarily through translation until it finds an object in its view. Then, the vehicle will run the code to execute the task it recognizes. The acoustic mode of navigation utilizes both the sonar and hydrophones to navigate to sonar-observable objects and pinger based missions, respectively.

Computer Vision

All missions rely on Computer Vision (CV) in order to achieve the most accurate navigation possible. Our AUV arrives to the general vicinity of the mission, then starts the CV program. Our computer vision program looks for the object - the mission or part of the mission we have to approach - and identifies it, moving forward until our AUV is directly above the object, following the object, or following a given path. We utilize many methods such as color identification and masking, contour approximation, finding object coordinates, erosions and dilations, blurring, and size isolation to achieve this year's missions. Both pre-recorded and live video streams taken directly from the testing pool were analyzed with the code in order to train our AUV for the competition. As seen on figures 7-13, we utilize all of the aforementioned methods to find the location of the gate. Figure 14 shows the output which includes: the percentage of the screen that each red dot covers and the x,y,x+width, and y+height (the top left and bottom right coordinates) of the bounding box are shown. These steps are used in a different order for every mission accomplished.



Figures 7-13: A progression of identification on the qualifying task gate.

```
0.0 0.3147632311977716 0.07985865724381626 0.8495821727019499
0.9257950530035336 0.39275766016713093
[[[113 298]]

 [[142 345]]

 [[144 358]]

 [[141 343]]]
0.07985865724381626 0.83008356545961 0.10247349823321555 1.0
0.9257950530035336 0.39275766016713093
Bounding Boxes:
[[1255.    0. 1364.  296.]
 [   0.  179.  115.  359.]
 [   0.  113.  113.  305.]
 [ 113.  298.  145.  359.]]
[x] after applying non-maximum, 4 bounding boxes
```

Figure 14: Returned coordinates which are then passed to navigation and propulsion.

III. Experimental Process and Results

A. *Software Testing*

Our team began working towards the development of an AUV starting March of 2019. Due to the fact that we started late into the competition season, time was among one of our biggest constraints. In order to create a competition-ready autonomous program, we needed to optimize our efficiency when we tested our solutions (navigational, data collection, vision). To do so, we relied heavily upon a benchtop setup for our tests; this setup was used to extract and process IMU data, and fine-tune functions in place of testing underwater, resulting in a minimal amount of downtime, and simulating the AUV in a more accessible format. While our custom AUV was being constructed, we relied on our BlueROV2 to conduct tests in the water, in a parallel prototyping environment. We utilized the BlueROV2 as a testing platform because it is a proven, robust commercial platform; it works "out of the box." Additionally, due to our AUVs being controlled by the same low-level flight controller, converting the program from the BlueROV2 to Orange proved to be a relatively seamless transition. Our lab has a swimming pool in which we performed a majority of our in-water testing of AUVs. We have conducted over 30 hours of in-pool testing. Additional daily testing will be conducted prior to the competition. Our testing warrants two main goals: collecting data and testing our programs. The collected data is then utilized to advance the development of our programs. During our journey, the team learned and documented lessons that can be reapplied in the future. Every team member, furthermore, compiled their weekly accomplishments through a weekly journal.

Additionally, every test was documented, with its purpose clearly defined, along with their results and its meanings also elaborated for any other team member to characterize and analyze.

Transition from simulation to the water

Among the greatest issues we encountered was the difference in results between running the program on the benchtop setup and deployment on our AUV. The first challenging navigational function we attempted to create and fine-tune was manipulating the "yaw" (rotation around the z-axis). Pieces of data from the IMU on our benchtop setup were extracted, and a function filtered the data to return degrees. We believed that we successfully created an "IMU turn" function, but once we attempted to deploy the function on our sub, many obstacles hindered us. We learned the importance of not underestimating the challenges that differences in environmental variables may present.

Calculations

We performed calculations to integrate into our program to make our code function more reliably. The extent to which calculations aid our program are: conversion of units, the direct variance between speed and time to move desired distances, the integration of actively reported velocity values to provide a position of the robot, the conversion of RGB values to HSV values, and the utilization of several Extended Kalman Filters to process the raw IMU values into comprehensible and accurate data. These calculations facilitated a reliable development of our autonomous program. These calculations were able to give us consistent results throughout our testing process.

Data Collection Procedure

Every test took place to collect a specific kind of data in regard to the function being developed. In the tests, we would evaluate the consistency of the data/trials resulting from the AUV. Every issue would be noted, a solution would be written, and the solution would be tested. If it worked, the solution was documented and run multiple times to once again evaluate the consistency of the test. To execute computer vision tests, we took pictures and videos underwater using the camera on our BlueROV2. These pictures/videos were then tested with the code. It was vital to ensure that CV code was tested on multiple images/videos in order to get the most accurate results.

IV. Acknowledgements

We would like to acknowledge our sponsors and mentors for their generous donations of resources and time. Team Inspiration would like to thank the following sponsors: Qualcomm, Northrop Grumman, Medtronic, Robo 3D, JetBrains, and Brain Corp. Without the support of these sponsors, the development and manufacturing of our AUV would not have been possible. We are grateful to our coaches and mentors: Alexander Szeto, Jack Silberman, Kris Chopper, Pamela Cosman, Amit Goel, Eric Lo, Pat McLaughlin, Venkat Rangan, Kunal Srivastava, Kenzo Tomitaka, and Dave Warner for providing invaluable advice. BlueROV2 is a great tool for us to learn from. We are also grateful for the discounts we received from various vendors. They are acknowledged in our team website. We appreciate Robonation/RoboSub organizers for putting the event together to challenge us. The RoboSub significantly challenged what we learned in last eight years with ground robots. Lastly, we are in-debt to our parents for their support.

References

[1] BlueROV2 Assembly Guide Series https://bluerobotics.com/learn/bluerov2-assembly/

[2] Flamax Studios, "Audio Injector Ultrasound 2", Flamax Studios, Sydney, AU, USA,October 15, 2018, Available: *https://www.kickstarter.com/projects/1250664710/audio-injector-ultra-2-sound-card/description*

[3] Liz Upton, "Bat Pi," Raspberry Pi, cambridge, EN, USA 10th Aug 2015, Available: https://www.raspberrypi.org/blog/bat-pi/

Appendix A: Expectations

Subjective Measures			
	Maximum points	Expected points	Points scored
The utility of the team website	50	40	
Technical Merit (from journal paper)	150	125	
Written Style (from journal paper)	50	40	
Capability for Autonomous Behavior (static judging)	100	90	
Creativity in System Design (static judging)	100	75	
Team Uniform (static judging)	10	10	
Team Video	50	50	
Pre-Qualifying Video	100	100	
Discretionary points (static judging)	40	35	
Total	650	565	
Performance Measures			
	Maximum points	Expected points	Points scored
Weight	See Table 1 / Vehicle	98	
Marker/Torpedo over weight or size by <10%	minus 500 / marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	300	
Gate: Pass through 60% section	200	0	
Gate: Pass through 40% section	400	400	
Gate: Style	+100 (8x max)	400	

Collect Pickup: Crucifix, Garlic	400 / object	0	
Follow the “Path” (2 total)	100 / segment	0	
Slay Vampires: Any, Called	300, 600	600	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	0	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	0	
Stake through Heart: Move the lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	1000	
Expose to Sunlight: Surface with object	400 / object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200 / object (Crucifix only)	0	
Random Pinger first task	500	0	
Random Pinger second task	1500	0	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	Tx100	0	

Appendix B: Component Specifications

Component	**Vendor**	**Model/Type**	**Specs**	**Cost (if new)**
BlueROV2	Blue Robotics			$6,595.28
Buoyancy control	Blue Robotics	LAST-A-FOAM® R-3318 2. Stainless Steel Ballast Weight 3. 2” series enclosure, 6” series enclosure	1.9in x 3.4in x 4.9in 2. (200 g, 7 oz) 3. Refer to Waterproof housing specs	Included in BlueROV 2
Frame	80/20 inc.	Series 10	10.63” x 20” x 22”	-
Waterproof housing	Blue Robotics	2” series enclosure, 6” series enclosure	6”: 322m length 2”: 322m length	Included in BlueROV 2
Waterproof connectors	Blue Robotics	M10 Cable Penetrator for 6mm Cable	Length: 25 mm BoltHead: 18 mm	Included in BlueROV 2
Thrusters	Blue Robotics	T200 Thrusters	Rotational Speed 300-3800 rev/min Length 4.45 in Diameter 3.9 in	Included in BlueROV 2
Motor control	Blue Robotics	Basic Electronics Speed Controllers	Voltage: 7-26 volts (2-6S) Max Current (Constant) 30amps (depending on cooling)	Included in BlueROV 2
Gripper	Blue Robotics	Newton subsea gripper		Included in BlueROV 2
Propellers	Blue Robotics	T200 propellers	Propeller Diameter 3.0 in Hub Diameter 1.6 in	Included in BlueROV 2
Battery	Blue Robotics	Lithium-ion Battery	https://bluerobotics.com/store/comm-control-power/batteries/battery-li-4s-18ah-r2-rp/ 14.8V, 18Ah (4 hours of continuous moderate usage)	Included in BlueROV 2

Component	**Vendor**	**Model/Type**	**Specs**	**Cost (if new)**
Converter	Blue Robotics	I2C level converter	Operating Voltage 3.3v - 5v Max Current @ 3.3v Vout 150 mA Output Connector 4 pin 0.1” header Input Connector 4 pin 0.1” header + JST-GH + DF13	Included in BlueROV 2
Regulator	Blue Robotics	5V 6A power supply	5V 6A power supply (converts 7-26 V)	Included in BlueROV 2
CPUs (2)	NVIDIA Jetson Nano	128 Core Maxwell GPU 10x80x39 mm		$188.00
External comm interface	N750 Wireless Dual Band Gigabit Router	TL-WDR4300	Simultaneous 2.4GHz 300Mbps and 5GHz 450Mbps connections for 750Mbps of total available bandwidth	N/A
Compass	Pixhawk	ST Micro LSM303D 3-axis 14-bit accelerometer / magnetometer	3-DOF Magnetometer (on the Pixhawk)	Included in BlueROV 2
Inertial measurement unit (IMU)	Pixhawk	Invensense® MPU 6000 3-axis accelerometer/gyroscope		Included in BlueROV 2
camera(s)	Blue Robotics	Low Light HD USB Camera	Pixel count - 2MP 1080P Onboard H.264 compression chip 32x32mm	Included in BlueROV 2
Hydrophones	Aquarian Audio & Scientific	AS-1 Hydrophone	Linear range: 1Hz to 100kHz ±2dB Horizontal Directivity(20kHz): ±0.2dB Horizontal Directivity (100kHz): ±1dB Vertical Directivity (20kHz): ±1dB Vertical Directivity (100kHz): +6dB -11dB	$395.00 each

Component	**Vendor**	**Model/Type**	**Specs**	**Cost (if new)**
Team size (number of people)	14	Student	Middle/high schoolers	priceless
Mentor consultation hours	many	Engineers	Professional	priceless
Testing time: test bench simulation	80 hours			
Testing time: in-water	30 hours			

Appendix C: Outreach Activities

Team Inspiration participated in many STEM-related outreach events to share our team's knowledge about robotics with others. We mentored many robotics teams, taught robotics camps and classes, organized and volunteered at robotics scrimmages and competitions, and reached out to youngsters at science museums and all major San Diego STEM fairs. Our volunteering has reached over 1,100 team hours each year in the last three years. To help promote robotics and engineering, we brought our AUV to the following outreaches:

- FIRST LEGO League (FLL) North American Open at Legoland
- Monthly Open Houses (held in our team's lab)
- Dingeman Elementary School Spring STEAM Carnival
- Meadowbrook Middle School FLL Interest Meeting

One large scale event that Team Inspiration took part in organizing was the California State Games, an amateur sports event. Due to our team's efforts, robotics tournament was introduced into the Games for the first time in their 30-year history. Team Inspiration also participated in the opening ceremony, where we shot frisbees into the crowd using a FIRST Robotics Competition robot (figure 15). This event was a great success and California State Games will continue to hold robotics as a sporting event. Team Inspiration has run several other robotics events during this season. One example of an event we have run is a FIRST LEGO League Scrimmage (figure 16).

Figure 15: One of our team members loads frisbees into a robot firing frisbees at the crowd at the opening ceremony of the California State Games.

Figure 16: Team Inspiration prepares the FLL teams for the scrimmage day.

Team Inspiration partners with local organizations around San Diego in order to spread the message of STEM around this community. One organization that Team Inspiration works with is Community

ConNext (formerly known as Include Autism), a local organization that focuses on integrating students with autism into society and to teach them skills for the future. Since 2016, Team Inspiration has held a monthly 30-minute workshop for 2-6 students, where we teach them how to build and program LEGO EV3 Mindstorms robots (figure 17).

Figure 17: Team members look on as participating students are running their sumo bots.

Besides spreading STEM locally, Team Inspiration also mentors a robotics team in Benin, West Africa, via Skype call every Sunday. We assist them by compiling resources, providing recommendations to their robot designs, and sending them robotics materials. With our team's assistance, U.S. Embassy's financial supports, and a local Benin organization, Team Benin is able to expand their robotics program to 13 + schools and reaching over 700 students (figure 18).

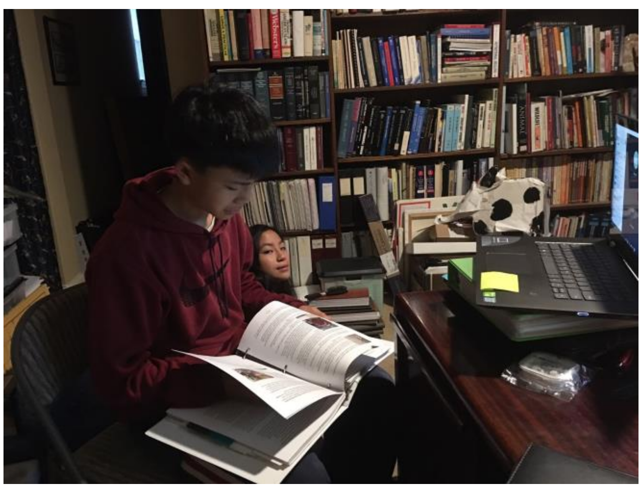


Figure 18: Due to the difference in time zones, our team members woke up at 6:00 AM on Sunday to call Team Benin.