BeagleBone Robotic Arm Controller

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1. Introduction

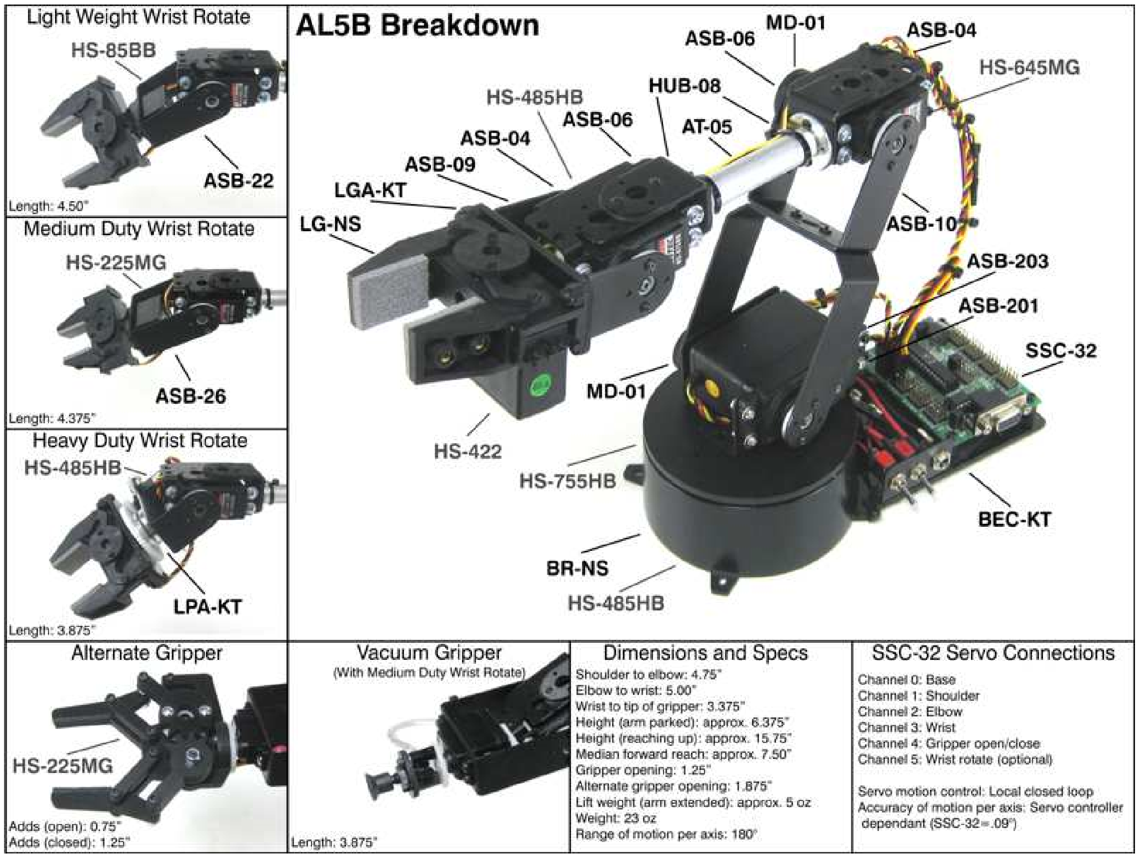
The Robotic Arm, known as the AL5A Robotic Arm features “base rotation, single plane shoulder, elbow, wrist motion, a functional gripper, and optional wrist rotate.”[1]. There have been several previous projects done with it, some with control via Windows Embedded [2][3] and one with Linux[4] [5]. The current project aims to interface it through a Beaglebone board [6]. The Beaglebone is a low cost development board that is able to boot off of a popular operating system such as Linux, and features network connectivity and serial interfacing.

It is intended to restore the state of the AL5A Arm to a point where one can control it remotely through the Beaglebone on an Internet connection. Monitoring the Arm through a Webcam is also within the scope of the project.

The AL5A Arm is operated via a series of Servo motors. The motors connect through the SSC-32 Servo controller, featuring MiniSSC-II emulation, which utilizes an Atmega 186 processor [7]. Servos are placed in ports 1-5 on the board, which communicates off of a RS-232 serial interface. The effective Baud rate is either 2400 or 9600, with 115200 for PC communication. Baud rate is defined as the oscillation of bits per second, which controls how often electronic pulses are received [8].

Under Linux, the serial inputs are seen as `ttyS0` or `ttyS1`. Searching with `dmesg` and using `grep` can help find the serial input. From there, the `minicom` utility can be used to interact with a serial interface, even if this interface is operated on USB protocol [9].

Since control of the SSC-32 chip is based on Atmel, AVR-libc is a library toolset to interact on a serial interface. This utility allows debugging, as well as systems level programming in C, the intended language of use for this project [10].



Dimensions and Specs

Shoulder to elbow: 4.75"
Elbow to wrist: 5.00"
Wrist to tip of gripper: 3.375"
Height (arm parked): approx. 6.375"
Height (reaching up): approx. 15.75"
Median forward reach: approx. 7.50"
Gripper opening: 1.25"
Alternate gripper opening: 1.875"
Lift weight (arm extended): approx. 5 oz
Weight: 23 oz
Range of motion per axis: 180°

SSC-32 Servo Connections

Channel 0: Base
Channel 1: Shoulder
Channel 2: Elbow
Channel 3: Wrist
Channel 4: Gripper open/close
Channel 5: Wrist rotate (optional)

Servo motion control: Local closed loop
Accuracy of motion per axis: Servo controller dependant (SSC-32=.09°)

Figure 1: Breakdown of Arm Assembly

Lynxmotion, which is the company that created the Arm Controller, supports the baud rate measurements with RIOS, the default program for configuring the SSC-32 controller [11]. Each component can be configured for position in degrees, as well as maximum grip. The gravity can also be compensated for, to allow for fine-tuned control when moving to specific angle degrees. Figure 1 displays an older version of the arm, which allows the rotation of components with regards to 180 degrees per axis.

2. Definition of the Problem

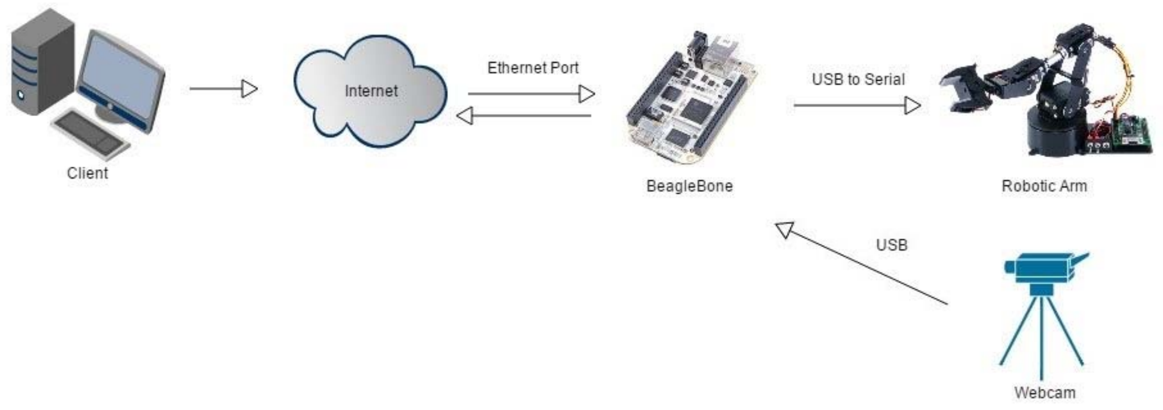


Figure 2: Physical Diagram of the System

The Physical Diagram of the system is shown in Figure 2. The Client sends the input command to the Beaglebone, which will then signal that a command was received. It will then send the signal of that command out to the Robotic Arm. This method does not involve error handling or any dangerous tasks that are carried out, but instead the commands received are completely carried out by the Robotic Arm. The Client is able to see the results via a Webcam that is connected to the Beaglebone.

The Client machine communicates with the Beaglebone via a Web Interface, and the Beagle Bone communicates with the Robotic Arm via USB-to-serial interface. The Webcam sends its images to the Beagle Bone for transmission to the Client.

Based on the functional description of the Beaglebone System (BBS), the software requirements can be formulated as follows:

1. The BBS shall accept button input via the Web Interface which will set a component of the arm to move.
2. The BBS shall accept input for each component of the arm via Web Interface, which is set as Arm Controller number, Position, and Speed.
3. The BBS shall accept text input via the Web Interface specifying one or multiple Arm components and their degrees of placement.

4. The BBS shall output an error message via the Web Interface if input components are formatted incorrectly.
5. The BBS shall output a status request via the Web Interface which will show the status of each Arm component by degrees.
6. The BBS shall output a display of the Robotic Arm's requested position via the Web Interface through a Web Camera stream.
7. The BBS shall output an error message via the Web Interface if the Arm is powered off.
8. The BBS shall output an error message via the Web Interface if the Arm is unable to move a component to a proposed position.

3. Design Description

From the software requirements, the two interacting pieces of software are the Web Interface and the BBS.

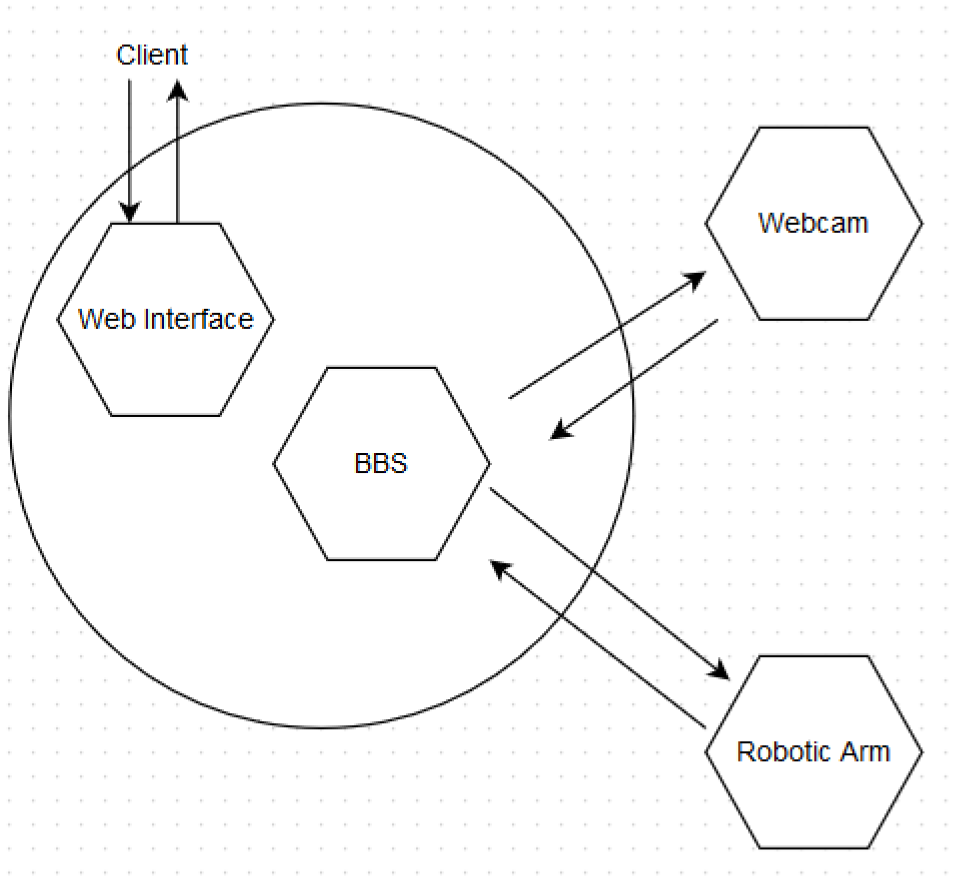


Figure 3 – Architectural Design

Figure 3 displays the system behavior of the BBS with respect to connected components. When a command is sent to the BBS from the Web Interface, it is verified and then send to the Robotic Arm. If executed, the BBS will send a confirmation to the Web Interface. The BBS will also take the stream of images offered by the webcam for the Client to view. While the BBS only sends command to the Arm, internally the BBS can monitor the state of the Arm and from there be able to communicate to the user if the Arm is offline.

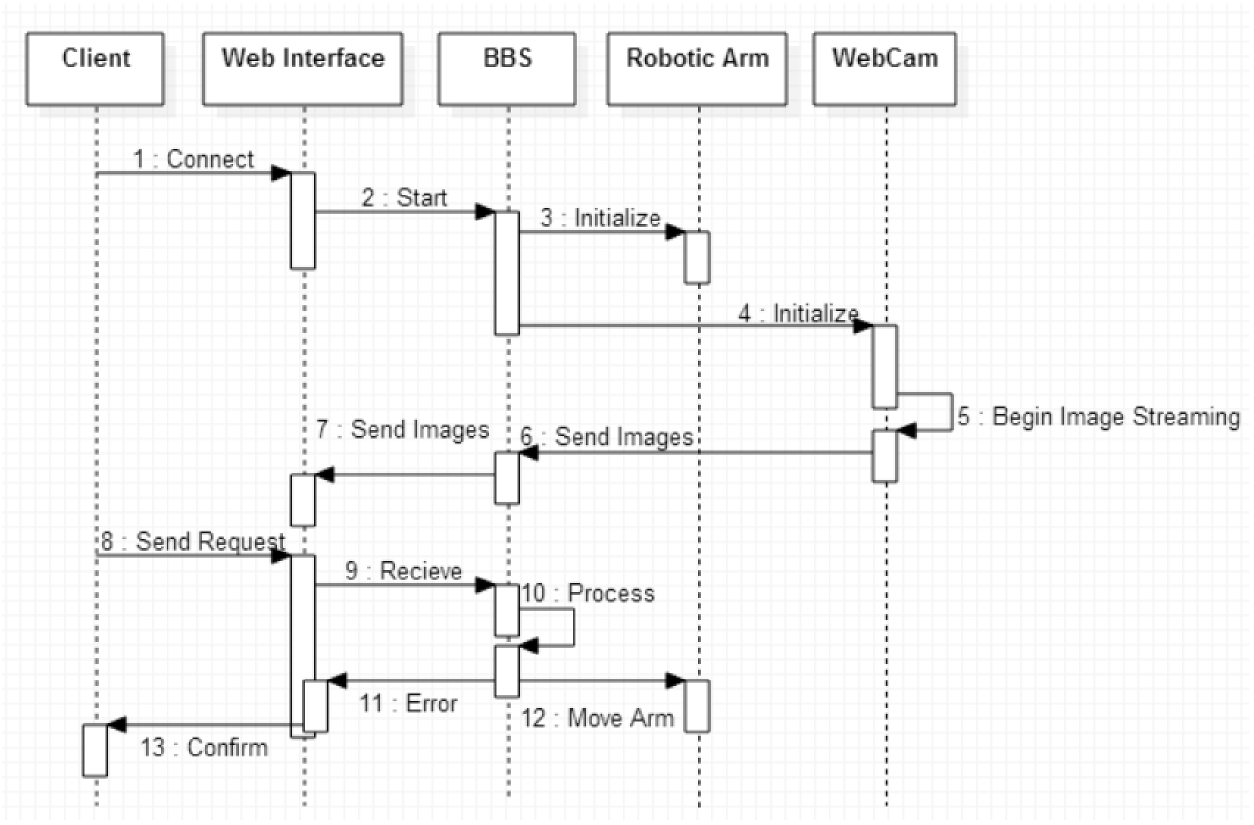
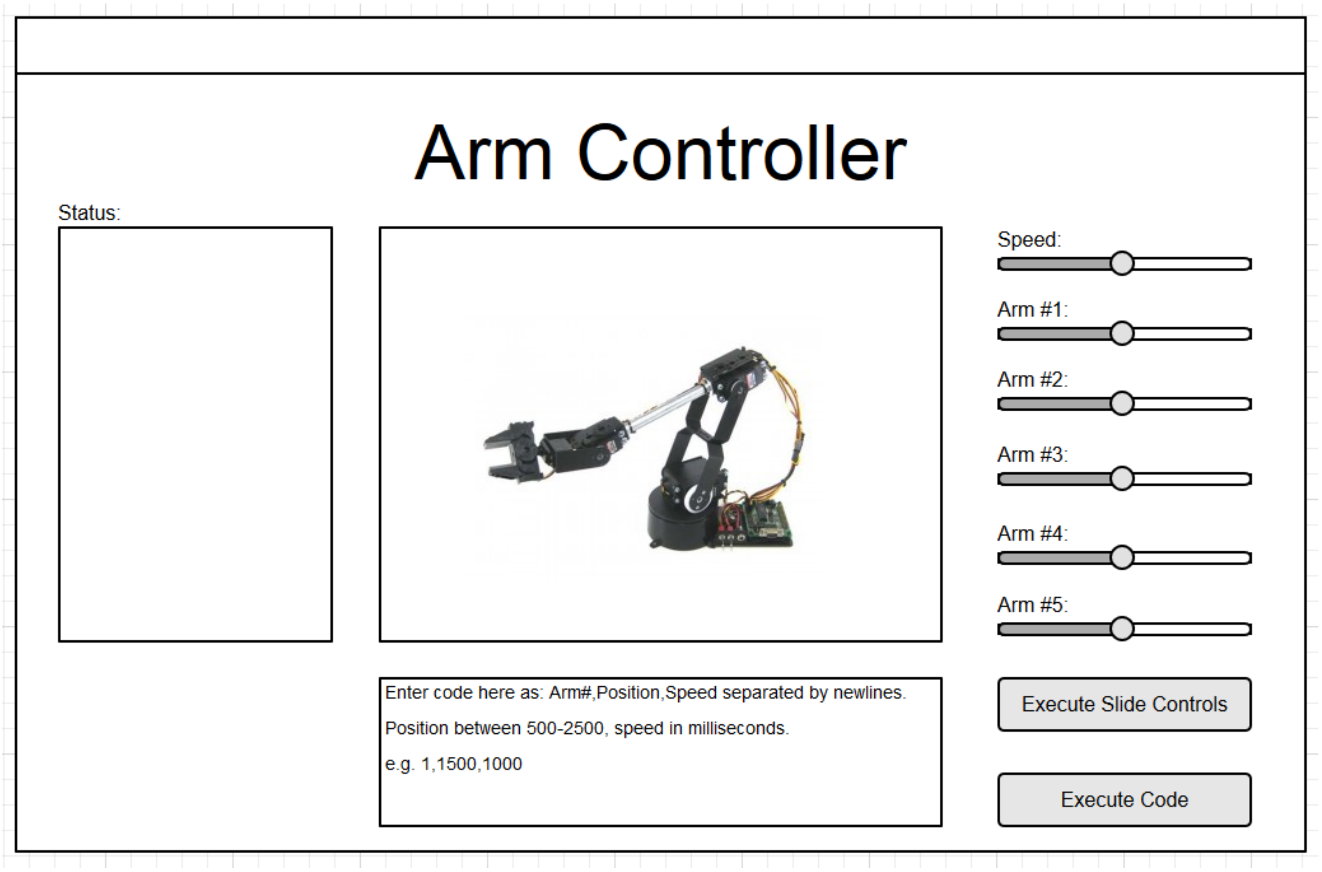


Figure 4: Sequence Diagram

Figure 4 describes behavior of the system at startup time. The Client connects to the Web Interface, which begins allowing the BBS to initialize any components that have not yet started. Before the Client sends a request, they already have an image feed from the Webcam. Once a request is sent, the BBS will be able to process internally and deliver any errors that might occur, such as the Robotic Arm being offline. One finished with processing and checking for errors, the BBS will move the ARM and the Web Interface will be able to send the confirmation message to the Client.



Enter code here as: Arm#,Position,Speed separated by newlines.
Position between 500-2500, speed in milliseconds.
e.g. 1,1500,1000

Figure 5: Web Interface

Figure 5 shows the Web Interface the user would face when operating the arm. Each of the sliders represent individual positions the arm can move in. The status on the left side will notify the user of any connection or parsing errors of the controller, and if it is currently in operation. At the bottom, custom code can be put in for the controller to follow. Each line contains the arm #, the position of the arm, and the speed that the arm moves. Selecting “Execute Slide Controls” will allow the arm to move according to the sliders, but will ignore the code. Selecting “Execute Code” will only execute the code that is in input, and ignore slider controls. First, the user code will be parsed, and if any errors are encountered, the Status window will display the issue.

4. Implementation

Initial implementation of the Robotic Arm involves communication with the standard for SSC-32 servo controller. The BBS is running Ubuntu 10.10, and the first activity was upgrading this to the latest version for ARM. The commands to update are as follows:

```
sudo apt-get install update
sudo apt-get install upgrade
```

Because of the nature of the lab it is necessary to activate the Ethernet port on the BBS, which is performed by:

```
sudo ifconfig eth0 up
sudo reboot
```

Since the SSC-32 operates with RS 232 communication standards, Ubuntu needs to recognize the connection interface of USB-to-Serial. The tools for this can be obtained through apt-get as:

```
sudo apt-get install stty termios gcc avr-libc
```

Once these components are installed, active development can begin. Rebooting the system allows you to `dmesg | grep tail` to view the recent component connections made. Stty automatically assigns the USB to serial port as `/dev/ttyUSB0`. This will be the basis of the connection.
To open the connection to serial the command will have to be used:

```
screen /dev/ttyS0 115200
```

Which will open a blank screen with a single “1”. Any characters entered are a direct feed to the serial port. To end the session, you type Ctrl-A, Shift-K and say yes to kill the session. Each time a carriage return is preformed (\r or enter on the keyboard), the SC-332 interprets the command. Commands can be formatted according to the firmware documentation from lynx motion [12].
An example command is:

```
#0 P1500 S1000 \r
```

Where # is followed directly by the servo motor you wish to control. P denotes the position of the motor that it is intended to be. P can be between 500 and 2500, where 1500 is considered “centered” for the servo. Inputting commands greater or less than the limits will only push the servo to the limit value. The S stands for speed in milliseconds to reach the intended point. Therefore, the position the servo will move to is 1500, and it will move for an entire second. If you place the S before the P, this acts as a timer where the servo will attempt to move to the correct position within the given time. In the current placement example, the servo can take longer than one second, but it will attempt not to.

Commands can also be grouped for the servo motor, and by arranging the time values for each input, the largest time constraint will win, but each motor can operate at different speeds. To execute the servo commands outside of the environment, the echo command must be used, preferably from a bash shell as:

```
echo –e “#1 P2500 #3 P750\r” > /dev/ttyUSB0
```

This ensures the command can go through for the serial port to interpret. To check the baud rate, the command:

```
Stty –f /dev/ttyUSB0
```

Will list all available options for the serial device. If any options are lacking, screen can reset the option by specifying it as a parameter.

5. Conclusion

For this project, communication between the BBS and the Arm Controller were completed, as well as connection to the Web Camera, viewable through a Web Interface. The BBS was able to open a file descriptor to the Serial Communications port in order to control the Arm, and any commands received from the Web Interface from a Client would carry out the command to the Arm.

For challenges in this project, the most major is lack of documentation and support for microcontrollers and the SSC-32 board in particular. Because the Arm Controller was purchased through a proprietary company, the only sure way to interface with it was through RIOS, which is the company software designed to work specifically on Windows operating systems. Since the BBS can only utilize Linux due to the ARM architecture, commands had to be highly customized for the SSC-32 to accept them.

Another major challenge is the age of the software stack. The most recent update to this system was in 2005, which was almost 10 years ago. However, within this time span, support for even the Lynxmotion RIOS system was difficult. Whether it is due to lack of interest of the product, or the rapid ageing of technology, supporting the Robotic Arm controller proved to be difficult.

Suggestions for future development would be automatic Arm movement. Because the Arm is able to respond to the BBS over the Web Interface, it would be trivial to include scripts onto the BBS itself that could control the Arm in unique ways. This could involve simple waves at a certain time, or a series of movements that can be extended to the Web Interface as a clickable button. On a more challenging note, the Web Camera on the BBS can be read from the image stream. Utilizing this stream, it may be possible to notice the position of the Arm, and a program could be developed for the Arm to interact with the environment. For instance, if a new object were placed within the vicinity of the Arm, and the Web Camera were able to detect the foreign object, the Arm could be manipulated to pick up the object and “toss it” (i.e., the servos would be prompted in an erratic manner to apply force and power along with a released grip). This would be recommended as a senior level project, and in some cases even a graduate level research subject.

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