NASA Solar Panel Design

MAY15-12

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Problem Statement

Our goal with this project is to be able to deploy a certain area of flexible solar panels in a system that is compact and lightweight. The system consists of three major components; the control circuit, boom and substrate/solar cell. The boom and solar array needs to be flexible enough to be stored inside a 1U (10 x 10 x 10cm) cube along with all other control mechanisms. Our target area for the deployed solar array needs to be between four and nine square feet. The solar cells may not have a bend radius less than 2.5cm. Sensors should be used to accurately relay the position/status of system components. The system must be designed in manner such that the solar cells can be deployed and retracted repeatedly after launch.

Deliverables

First Semester

- Research Low Earth Orbit space
  - Temperature Range
  - Deterioration due to Radiation Levels
  - Altitude Range
  - Vacuum Conditions/Pressure
- Circuit Design
  - Analog vs. Digital Design
    - Reliability/Cost
    - Materials
    - Size constraints
    - Fabrication/Implementation
    - Testing
    - Design Simplicity
  - Machine to Machine Interface
    - Controls
    - Drivers
    - Motors
    - Sensors
  - Human Machine Interface Component
    - Command Interpretation
    - System Feedback
  - Communication in a vacuum
- Boom Design
  - Analyze varying design concepts
    - Scissor Jack
    - Umbrella
    - Tape Measure
    - Silk Fan

        - Telescoping Antenna
        - Origami
    - Torque Requirements
    - Friction
    - Weight
    - Structural Rigidity
    - Mass Production
    - Proof of Concept
- Material Specification
    - Prototype vs. Production Materials
    - Space Worthiness
    - Weight
    - Durability
    - Friction Coefficients
    - Structural Rigidity
    - Finalize Bill of Materials
    - Lead Time
    - Order parts for Prototype
- Keep track of ways to improve

Second Semester

- Complete Circuit Fabrication/Programmed
- Conduct circuit testing
- Make necessary changes
- Have circuit shipped to NASA for testing
- Write Final Report

Specifications

Design Constraints

- Stored within 1U (10 x 10 x10cm)
- Deployed Solar Array area (4 to 9 square feet)
- Weight to area ratio

Hardware Specification

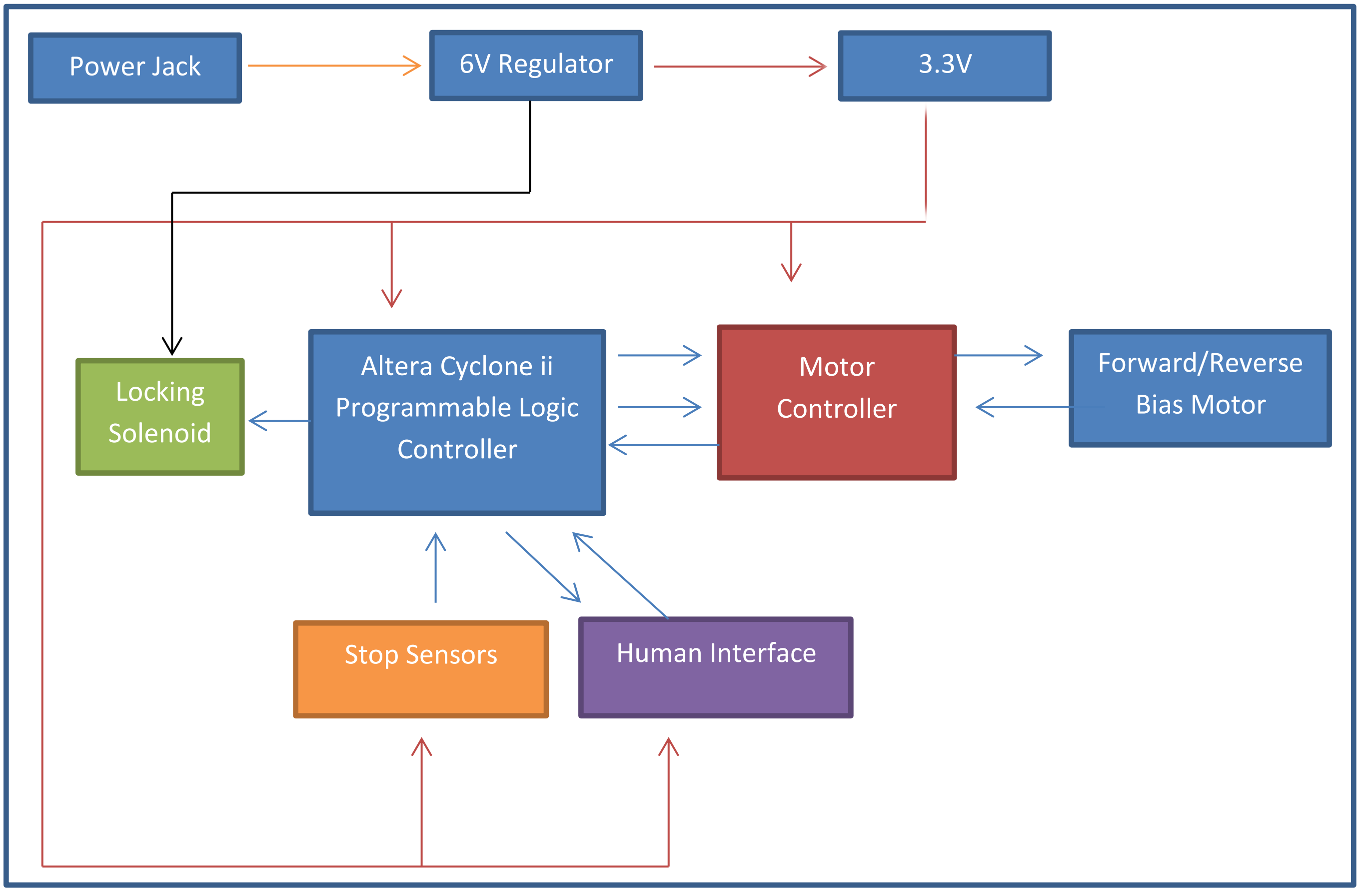

Figure 1 *System Schematic*

For our design we are using an Altera Cyclone II Programmable Logic Controller. This PLC can simulate a wide array of logic systems but uses solid state components instead of relying on several physical logic gates. Overall all this will increase the reliability of the system and allows minor changes to several systems to occur without changing the building process. In our system the PLC will:

- Conduct all of the logic processes
- Accept inputs from sensors to determine the state of the system
- Send/Receive information to the end user to make further decisions
- Send start/stop signal to the motor controller

This acts as the main controller for the entire system. All inputs and outputs are run through our PLC for processing before being sent to another part of the system. This ensures that the entire system is acting in unison and nothing is being over looked. The PLC has been programed to the specifications as outlined below.

For the test example we are using an Altera Cyclone II Programmable Logic Controller. This PLC can simulate a wide array of logic systems but uses solid state components instead of relying on several discrete logic gates. Overall all this will increase the reliability of the system and allows minor changes to several systems to occur without changing the building process. In our system the PLC will:

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The logic controller for this design is based off an Altera Field Programmable Gate Array (FPGA). This microprocessor was chosen for its inherent ability to execute logic arrays in a fast and reliable manor. The AT40KEL040 used in our design is made for use in LEO due to its functionality and durability. The chip is not degraded by radiation and can withstand extreme temperatures. This was a major deciding factor when compared to other options. Various Programmable Logic Controllers (PLC) were evaluated but were not certified to environment specifications necessary for our design. The chip/board combination can support all necessary logic functions while maintaining functionality.

Table 1 below illustrates the specifications of our device family:

Table 1 AT40KEL040

Device	AT40K05	AT40K10	AT40K20	AT40K40
Usable Gates	5K – 10K	10K – 20K	20K – 30K	40K – 50K
Rows x Columns	16 x 16	24 x 24	32 x 32	48 x 48
Cells	256	576	1,024	2,304
Registers	256(1)	576(1)	1,024(1)	2,304(1)
RAM Bits	2,048	4,608	8,192	18,432
I/O (Maximum)	128	192	256	384

For our Simulation we may use the comparable Cyclone II (as found in the EE281 lab). These chips perform similarly without the cost of purchasing the actual component as described.

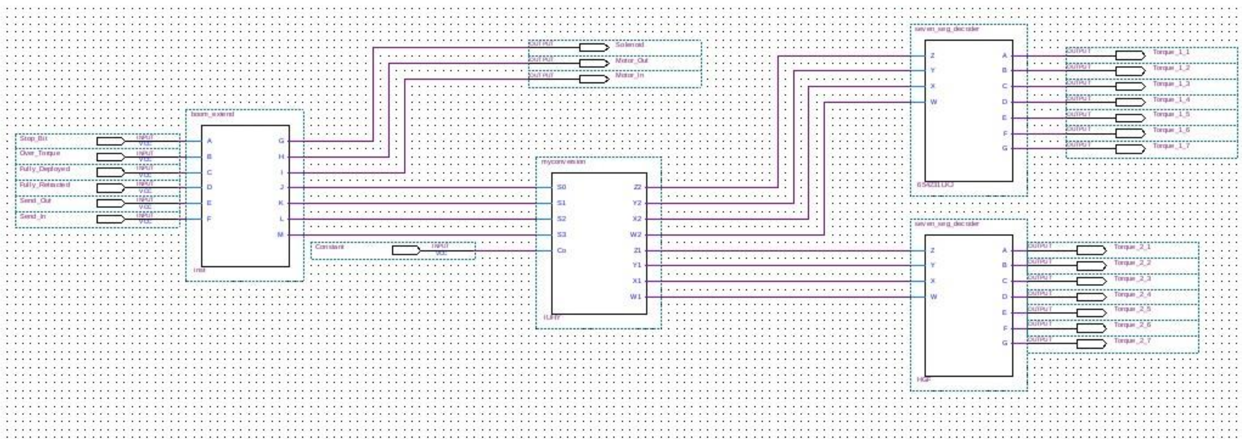

Figure 2 Quartus II Logic Layout

Table 2 Verilog Code for Boom_Extend Moduel

```
module boom_extend (A,B,C,D,E,F,G,H,I,J,K,L,M);
input A,B,C,D,E,F;
output G,H,I,J,K,L,M;
        assign G = (~A & ~B & ~C & E & ~F) + (~B & ~C & ~D & E & ~F) + (~A & ~B & C & ~D & E);
        assign H = (~A & ~B & ~C & E & ~F);
        assign I = (~A & ~B & ~D & ~E & F);
        assign J = (C & E) + (C & D) + B + A ;
        assign K = ((~B & ~C & D & ~E) + (~B & ~C & D & F) + (~B & C & ~D & ~E & ~F) + (B & ~C
                & ~D & ~E & F) + (B & ~C & ~D & E & ~F) + A);
        assign L = (~B & ~C & E) + (C & ~E & ~F) + (C & D) + (B & ~E & ~F) + (B & D) + (B & C) + A
                + (~C & E & F);
        assign M = (~A & ~C & ~E & F) + (~A & ~D & F) + (~A & C & ~D & ~E) + (~A & B & ~E)
                +(~A & B & D) + (~A & B & C) + (A & ~B & ~C & ~D & E & ~F);
endmodule
```

Table 3 Verilog Code for Seven Segment Decoder

```
module seven_seg_decoder (A,B,C,D,E,F,G,Z,Y,X,W);
input Z,Y,X,W;
output A,B,C,D,E,F,G;
        assign A=((~Z&~Y&~X&W)|(~Z&Y&~X&~W)|(Z&~Y&X&W)|(Z&Y&~X&W));
        assign B=((~Z&Y&~X&W)|(~Z&Y&X&~W)|(Z&~Y&X&W)|(Z&Y&~X&~W)|(Z&Y&X&~W)|(Z&Y&X&W));
        assign C=((~Z&~Y&X&~W)|(Z&Y&~X&~W)|(Z&Y&X&~W)|(Z&Y&X&W));
        assign D=((~Z&~Y&~X&W)|(~Z&Y&~X&~W)|(~Z&Y&X&W)|(Z&~Y&X&~W)|(Z&Y&X&W)|(Z&~Y&X&~W));
        assign E=((~Z&~Y&~X&W)|(~Z&~Y&X&W)|(~Z&Y&~X&~W)|(~Z&Y&~X&W)|(~Z&Y&X&W)|(Z&~Y&~X&W));
        assign F=((~Z&~Y&~X&W)|(~Z&~Y&X&~W)|(~Z&~Y&X&W)|(~Z&Y&X&W)|(Z&Y&~X&W));
        assign G=((~Z&~Y&~X&~W)|(~Z&~Y&~X&W)|(~Z&Y&X&W)|(Z&Y&~X&~W));
endmodule
```

For the actual Cubesat an Atmel® AT40KEL chip will be used due to its design. This chip has been produced for space use and can withstand the environmental conditions it will be exposed to. When paired with the MQFPF 256 Development Board the AT40KEL has 233 user definable input/output pins which support the necessary configuration.

Motor Controller

The motor controller has been added to the system to allow the motor the appropriate voltage needed to power the boom while still being able to accept 3.3V signals from the PLC. This also allows a secondary system to interpret the torque sensor from the motor before that information is sent to the PLC. The motor controller is programed to send a signal once the torque goes outside set bounds. The torque sensor is built into the motor controller which adds an additional layer of protection. The activation of this sensor will automatically send a stop signal to the motor and sends a warning signal that an over-torque event is occurring to the end user through the human interface.

Forward/Reverse Bias Motor

For our system we are using a forward and reverse bias electric motor capable of at least 30 inch-pounds of torque. This will give sufficient power to extend and reverse the boom in the microgravity environment. We have also included a buffer zone of 50% torque to ensure the motor will have sufficient torque. The motor chosen must also lock in place when power is not applied. This will decrease the power consumption of the system and ensure the boom stays in the extended or retracted position.

Human Interface

The human interface portion of our system consists of two 7-segment LCD displays and three 2-position switches. The two seven-segment displays relay position information that can be understood by the end user using the table below. The position information values will correspond to a set table of values where each value corresponds to different situations as shown below. All of these components are powered off of the 3.3V power supply.

Table 4 Feedback Values

Value Displayed	Meaning
0	No signal
1	Send in signal received, motor Reverse Powered, Solenoid Pullen In
2	Send out signal received, motor Forward activated and solenoid powered out
3	Send out and in signals received
4	Fully Retracted Success
5	Fully Retracted and Send in signal received
6	Fully Retracted, receiving signal to send out and in
7	Fully Deployed Success, solenoid no longer powered
8	Fully deployed but still receiving signal to send out, solenoid still energized to push out
9	Fully Deployed but receiving signal to send out and in, solenoid still energized to push out
10	Receiving fully deployed and fully retracted signal and possibly others
11	Over torque signal received
12	Over torque signal received while deploying, motor stopped

13	Over torque signal received while retracting, motor stopped
14	Stop Bit Received
15	Stop Bit Received while sending out, solendoid powered

Stop Sensors

At each end of the screw that moves the boom there are contact sensors. When the boom reaches these sensors a signal is sent to the PLC that stops the motors and sends this information back to the end user through the human interface. These normally open contacts close then activated sending a 3.3V signal.

Table 5 I/O Pins

Node Name	Direction	Location	I/O Bank	Fitter Location	I/O Status	Current Strength
Boom Extend	Input	PIN_AD13	8	PIN_AD13	3.3 V	24mA
Boom Retract	Input	PIN_AF14	7	PIN_AF14	3.3 V	24Ma
Motor Forward	Output	PIN_AE23	7	PIN_AE23	3.3 V	24mA
Motor Reverse	Output	PIN_AF23	7	PIN_AF23	3.3 V	24mA
Pressure Sensor	Input	PIN_N26	5	PIN_N26	3.3 V	24mA
Stop Signal	Input	PIN_N25	5	PIN_N25	3.3 V	24mA
Retract Stop	Input	PIN_P25	6	PIN_P25	3.3 V	24mA
Extend Stop	Input	PIN_AE14	7	PIN_AE14	3.3 V	24mA
LCD_1	Output	PIN_L3	2	PIN_L3	3.3 V	24mA
LCD_2	Output	PIN_L2	2	PIN_L2	3.3 V	24mA
LCD_3	Output	PIN_L9	2	PIN_L9	3.3 V	24mA
LCD_4	Output	PIN_L6	2	PIN_L6	3.3 V	24mA
LCD_5	Output	PIN_L7	2	PIN_L7	3.3 V	24mA
LCD_6	Output	PIN_P9	2	PIN_P9	3.3 V	24mA
LCD_7	Output	PIN_N9	2	PIN_N9	3.3 V	24mA

Solenoid

A solenoid is composed of a coil wound around a hollow tube within which a ferrous material is placed. By energizing the coil, the ferrous core is either pulled into or pushed out of the coil. The latching mechanism will be used to hold the boom at full extension and relieve tension from the drive rollers. The latching mechanism will have a shaft that is inserted through the tape measure style boom, perpendicularly, and will need to consume no power while in either the extended or retracted state. We found a few solenoids that may work, but have settled on a C-Frame Magnetic Latching Solenoid from Bicron Electronics Company. The Magnetic Latching function of the solenoid means that the coil needs to be energized to move the core, but the core will remain in its final position until the coil is re-energized with opposite polarity.

The solenoid listed above has been chosen because of the price point and the way it functions. Two solenoids in each of two configurations have been procured for testing and possible implementation, free of charge (Part Numbers: SC0424L2410 and SC0424L0625). The sales representative from Bicron Electronics did ask that we return some basic testing data if the solenoids are used. The specifications of the Bicron Solenoid, as far as length and force of pull, are 0.08 inches of pull at approximately 10 ounces of force. The solenoid is rated at 6 volts and has dimensions of 1.1 X 1.1 X 2.4cm. Bicron electronics has the in-house capability to produce custom aerospace rated solenoids with relatively short lead time (around five to ten days to begin prototyping). During actual implementation, it may be better to have an aerospace rated solenoid.

Bearings

The roll for the solar cells we are using needs to be at least 5 cm in diameter and will be placed over a rod that is connected to each side of the box. The bearings that we are using for our prototype will be 0.75" bore x 1-5/8" OD x ½" W. These are single row bearings made of steel, and are filled with 35% grease. These will be purchased from Fastenal because we are asked to use off the shelf parts and we feel that this will satisfy our needs here but we will be advising NASA to use different materials for space applications.

We need bearings for our design and have found multiple products, companies and types that would work. Here are a few the options that we turned down. The 3030 single seal from RBC Bearings. These bearings are made from hardened steel, have a nylon retainer, and are pre greased. The speed range on these bearings are for 2500 to 3000 RPMs. These have been tested for aerospace applications and would be well suited for what we are looking for. These would be great to use but we feel the ones from Fastenal are more suited for our needs and our budget.

Lubrication

Next we need to look at what lubricants can be used for our demonstration and for space applications. For our demonstration the lubrication already found in the Fastenal bearings will work great for our on earth applications. Now NASA has posted documents on what lubricants they use. NASA is against using oil and grease due to the difficulty of applying it and the temperatures it can withstand. For this reason NASA prefers to use solid lubricants and uses liquid and gas lubricants only if they have to. MoS_2 has a low coefficient of friction in a vacuum and in the atmosphere. This looks to be the lubricant of choice followed by graphite, PTFE or Vespel, and other soft metals.

Software Specification

We will be using a PLC to operate all controls in the design. The PLC will be programmed with Altera Quartus II software using code written in Verilog, an IEEE standardized hardware description language commonly used for digital logic programming. Using the Verilog language for programming ensures quick and easy reproducibility by our client, as the PLC is prefabbed. Therefore, the only remaining task once the PLC has been received is to load the program and attach the board the CubeSat. Once fully assembled and deployed, a signal will be received from the operator and interpreted by the PLC, which will execute the command while monitoring for problems.

Basic Operations:

PLC

- The system must be able to receive a deployment signal from the operator.
- The system must be able to interpret the received extension signal.
- The system must be able to execute the deployment command.
- The system must be able to receive an error for excessive boom tension, indicating a problem with deployment.
- The system must be able to automatically stop deployment at full extension.
- The system must be able to return a signal that the boom successfully extended.
- The system must be able to latch the extended boom in place.
- The system must be able to receive a retraction signal from the operator.
- The system must be able to interpret the received retraction signal.
- The system must be able to unlatch the boom.
- The system must be able to execute the retraction command.
- The system must be able to receive an error for excessive boom tension, indicating a problem with retraction.
- The system must be able to automatically stop retraction at full retraction.
- The system must be able to return a signal that the boom successfully retracted.
- The system must be able to receive a stop signal to interrupt deployment or retraction during any step of command execution.

Note: The communication between the base station (operator) and the satellite will be taken care of by NASA.

We will be using a motor controller to determine the torque which the motor is exerting on the shaft during operation. By using our knowledge from classes, we know that the harder a motor is working, the electric potential across the input terminals will decrease and the current draw will increase. By monitoring these values in comparison to predetermined threshold values, we can monitor for torque and locked rotor conditions.

Motor Control Circuit

- The system should be able to measure current draw.
- The system should be able to measure electric potential.
- The system should be able to decide which threshold range the values fall into.
- The system should be able to determine what needs to be done within that threshold range.
- The system should be able to return a decision to the PLC.
- The system should be able to constantly iterate these checks and evaluations during boom operation.

Based on the requirements for this motor control circuit, we have found a motor controller that will meet the minimum specifications required to drive a motor for our application. The motor controller that has been located should take only minimum programming to set the threshold values for our system.

Boom Design

The solar panels will be supported by a scissor type boom. When retracted the boom will fit completely inside of the cube satellite. The individual parts of the boom will be built as shown below.

Our boom will consist of two measuring tapes stitched back to back to form a triangular shape, similar to the TRAC (Triangular Rollable and Collapsible) Boom constructed by the AFRL (Air Force Research Laboratory) for NASA's Nanosail-D Project. For the prototype deployment mechanism we will be using standard aluminum measuring tapes to keep costs to a minimum.

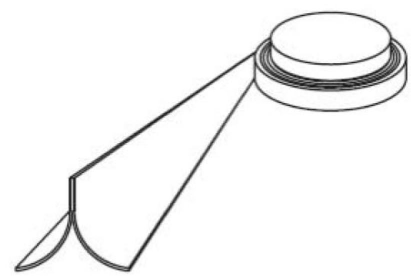

Figure 3 Tape Boom

The guide plate for the boom will need to keep the boom in its triangular shape, as seen in Figure ASDFG below (taken from the AFRL thesis paper for the TRAC boom project). Once retracted the triangular shape can be pressed flat and wound tightly around a shaft for storage, as seen in Figure 18 (taken from the AFRL thesis paper for the TRAC boom project). This arrangement has already been proven to meet structural rigidity requirements at extensions up to thirteen feet in testing conducted by the AFRL.

Figure 4 Boom Exiting

The TRAC boom is comprised of a stainless steel alloy called Elgiloy for a number of reasons:

1. Possession of the structural composition for repeatable boom extensions and retractions.
2. Reduction of fissures in the seam welds when wrapped repeatedly.
3. Resistance to seam weld oxidation.
4. Increased material integrity.

Elgiloy has a coefficient of elasticity of E=190 GPa, a maximum strain of 1%, and a density of 8.3 g/cm^3. Being an extremely light material with decent rigidity and little deflection at the lengths we will be using, it has been recommended that Elgiloy is used for final implementation.

Schedule

Due Date	Tasks	Team Assignments
10/5/2014	**Wired Filters or PLC Paper**	
	Design Simplicity	Luke
	Size	Dustin
	Cost	Tom/Isaac
	Reliability	Tom/Isaac
	Fabrication	Antjuan/Ryan/Anh
	Implementation	Antjuan/Ryan/Anh
	Testing	Antjuan/Ryan/Anh
10/31/2014	**Circuit Outline and Improvements**	Team
11/1/2014	**Our design constraints were changed**	Team
11/12/2014	**Redesign inside of 1U box**	
	3D Model, size and position	Ryan
	Motor	Luke/Antjuan
	Motor Controller	Antjuan
	Locking Mechanism	Tom
	Choose PLC	Team
	Constant force spring	Ryan
	Rollers	Ryan
	Tactile bump sensor	Isaac
	1U Holding Compartment	Tom/Isaac
	Re work logic	Luke
	Bearings and Lubricants	Dustin
11/26/2014	**Final circuit completion**	Team
	Material Selections	Anh
	Bill Of Materials	Team
12/1/2014	**Material Ordering**	Team
12/12/2014	**Draft Design and BOM sent to NASA**	Team
1/30/2015	**Circuit Assembled**	Team
2/6/2015	**On surface Testing**	Team

2/20/2015	**Testing Compleation**	Team
	Ship Circuit to NASA	Team
	Boom Design	Team

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