7th Annual Gateway Arch Engineering Competition
Christian Brothers College High School
Float the Dock!
2023

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Jacob Bray 2026
Sean Edmiston 2027

Benjamin O'Daniels 2024
Kaleb Elpers 2026
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1. Defining the Problem

The St. Louis riverfront is the cradle of development in the region from as early as the mid 1700's. For much of its history, St. Louis was defined by the commerce transpiring along the Mississippi River. Even though the modern focus celebrating this tradition is the Gateway Arch National Park, riverboat tourism long predates the Arch itself. Gateway Arch Riverboats have been cruising the river since 1910, offering sightseeing, dinner, and specialty cruises as well as private charters. The enterprise is based on a 303-foot dock, consisting of 4 barges, just down the steps from the Gateway Arch. This location, however, does pose some challenges. "The Mighty Mississippi" can be unpredictable and dangerous, even on its best days. Weather conditions throughout the middle third of the United States all funnel down the Mississippi, and when they reach the 30-mile stretch in St. Louis, it is not uncommon to see great fluctuations, up to fifty feet in level, as well as the accompanying widening and the detritus that may be caught in its flow. Rapidly changing conditions make anchoring a dock troublesome. Currently, manual, and frequent adjustments are required to the five cables used to moor the dock during changing conditions. Without these adjustments, the ramps to the dock could be submerged and unusable, or the dock may run aground. We have been tasked to engineer a system that automatically adjusts the dock to the appropriate level as the river rises and falls.

2. System Overview

To provide an autonomous system for adjusting the dock, there are many factors to consider. Most notably is the unpredictable nature of the Mississippi River and the sheer power it possesses. Many aspects can go wrong very quickly. To mitigate this issue, we decided that our solution would not just automate the dock, but serve as a monitor, control, and alerting system for the overall status of the dock as it relates to its environment. To perform these functions, we looked at our own school building. Complicated problems often require complicated solutions, and the HVAC system on a school such as CBC is no exception. From controlling massive cooling towers on the roof down to the individual classroom temperatures, there are many layers needed to efficiently operate and integrate the parts. Just like our HVAC system, the heart of our dock solution is a web application. This application provides not only status of the overall system and individual subsystems, but provides user override, control, situational awareness, and alerting. In addition, having software at the core of the solution allows the system to be upgraded, refined, or even self-improved with machine learning algorithms.

The primary function of the system is to adjust the placement of the dock relative to the shoreline as the water level rises and falls. To do this, we propose integration of several subsystems, including river conditions, ramp status, mooring cables, bow thrusters, utility connections to the shore, and remote visual monitoring. The integration of the subsystems includes feedback and crosschecks to ensure safety and reliability, while the user can quickly and easily monitor and control subsystems to fit specific case needs.

3. MCA Application

The heart of our proposed design is a computer application that allows monitoring, control, and alerting (MCA) of key subsystems used in our integrated solution. We were inspired by the UI model common in Johnson HVAC controls that is in use in our own school building. (Screenshots of this system are shown in Appendix.) The control application has an inherent hierarchy that allows macro system monitoring, control and alerting (i.e, status of the dock position relative to the shore), with the ability to access individual subsystems for more refined monitoring, control, and alerting. Monitoring of the subsystems may involve an animated representation, tabular data, or graphical data. Control may include software sliders, direct entry, or check boxes. In-application alerting may include yellow (caution) flags or red (required action) flags. Serious alert conditions may include automated text messages or emails. The alert limits will be set by the end user, and may be refined through usage, or optionally, machine learning algorithms. The refresh rate of the system monitor, control, and alert will be hourly, with a user option for modification.

The cost of the application development can be segmented between data storage and design implementation. The former should cost $4 a month for storage of 1 terabyte assuming the s3 Intelligent-Tiering Archive Instant Access tier plan. Concerning the latter, the cost for it was determined through assuming a medium sized company to develop the application, and for the task to be completed in 250 hours. Provided that the company pricing is consistent with that standard for the industry, the price per man hour is approximately $140 so the estimated total price for the project is $35,000.

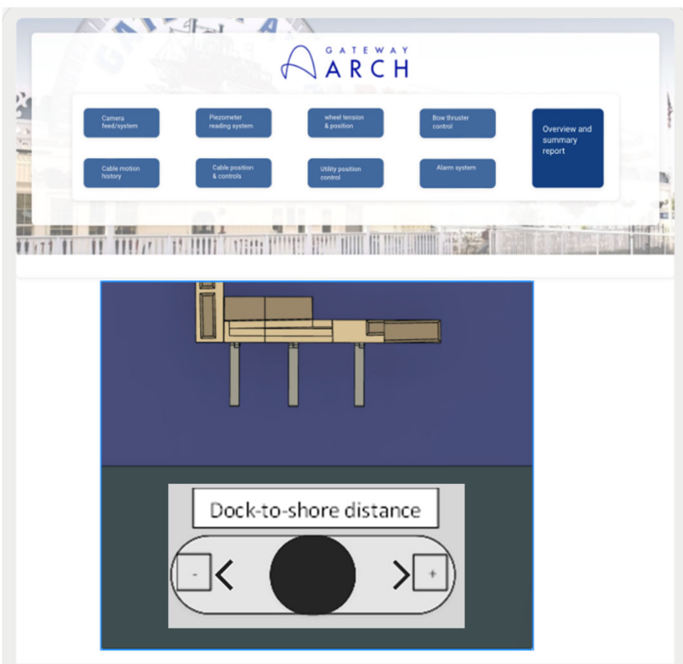

Figure: MCA app home page. Monitors overall distance to shore, provides input to move dock closer or away from shore.

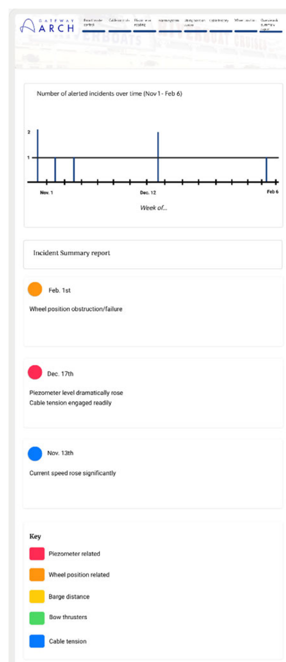

Figure: System level alert page

3.1 River Conditions

The first subsystem view is situational awareness of current river conditions. This page is monitor and alerting only. It will display real-time river level data from the National Oceanic and Atmospheric Administration (NOAA). This data, updated hourly, is available on the internet. The application will alert the user to a maximum and minimum river level in which the autonomous system has reached operational limits. As an option, this page could display local river conditions from an array of Army Corps of Engineers piezometers that are located along the 30-mile St. Louis riverfront area. Another option could be a display of conditions at the dock, such as meteorological data or current speed (which would require additional sensors on the barge).

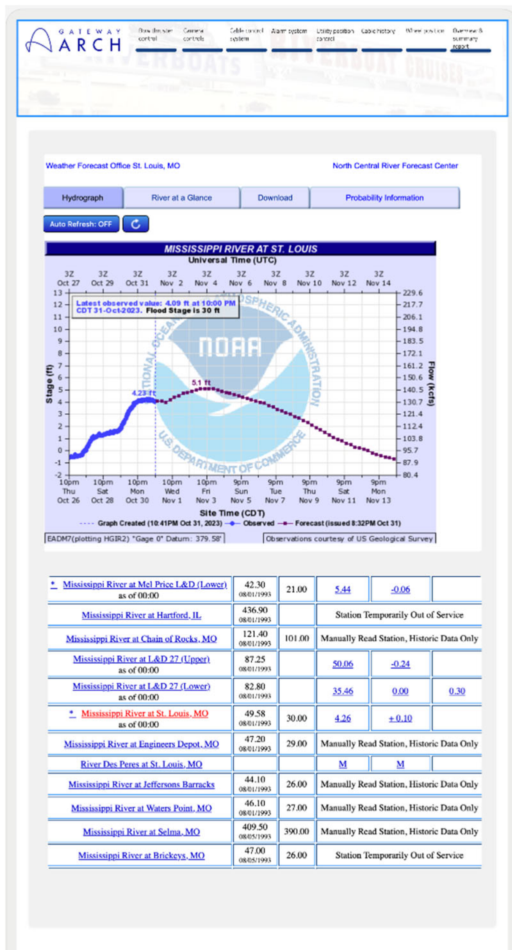

Figure: River conditions page

3.2 Ramp Status

The primary input to our autonomous system is the ramp status. As shown in the diagram, when the dock is the preferred distance away from the shoreline, the ramp will be approximately level. As the river level rises, the dock must be moved toward the shore. As the river level falls, the dock must be moved away from the shoreline. If these adjustments are not made, the angle of the ramp will no longer be level. When the ramp moves out of level, our system will respond. The status of all three ramps will be monitored and compared, with alerts for incongruous readings.

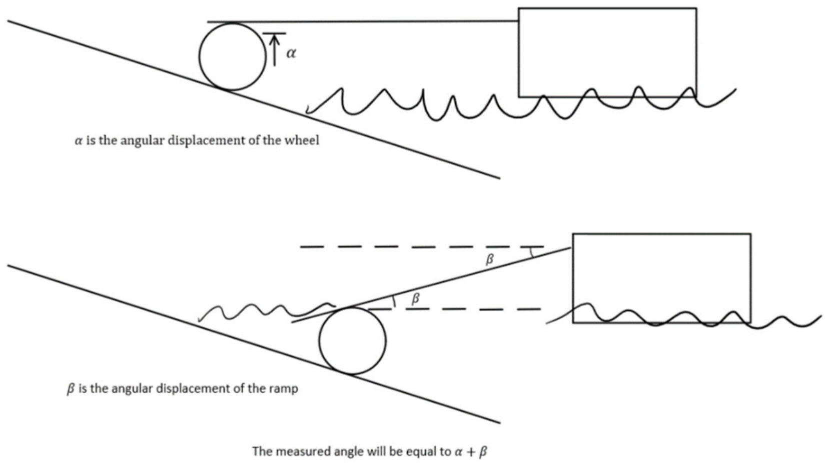

Figure: ramp geometry showing normal configuration and river high configuration. The bottom situation would trigger an alert.

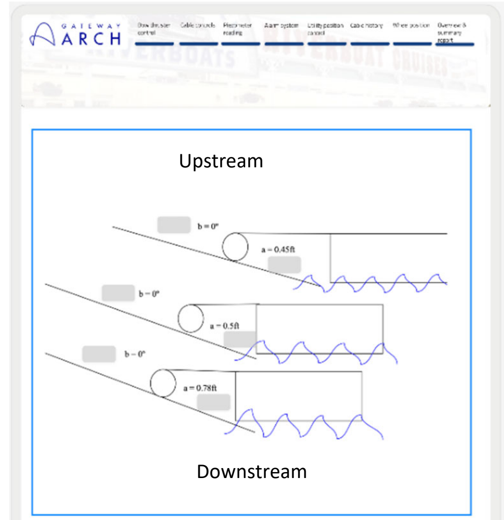

Figure: Ramp status page

To measure the ramp angle, we will track the position of the wheels using a magnetic encoder attached to the wheels to keep track of the angle (rotation) of the wheels. This will indicate to the system when the maximum and minimum extents of normal river levels are exceeded. The whole system includes a magnetic encoder as a target, and a sensor that tracks the poles of the magnet, giving the angle. The cost per set of the encoder and the target is between about $1200 and $1300, depending on the dimensions and resolution of each part, bringing the total to $7200-$7800. Using the angle outputs from two different refreshes (moment the sensor "measures" and gives a value), the distance calculation the wheels have moved can be determined using the radius of the wheels and the angle, in radians, that the wheels have moved. Using the initial positions of the wheels when the magnetic encoders have been installed will allow for an accurate tracking of where the wheels are up the bank. The data from the encoders would be collected each time there is a refresh (including when the application is opened), which because the wheels are not going to be moving fast, will be accurate enough to collect enough data to track the wheels.

We will also measure the ramp angle on the dock side. The ramp angle will also be measured with the magnetic encoder. The magnetic encoder will measure when the ramp angle has adjusted by making the traditional angle of the ramp zero. By zeroing the traditional angle of the ramp, the magnetic encoder will be able to read if the angle has increased or decreased. The magnetic encoder will be placed at the hinge where the ramp and the barge are connected.

Using the values for the angle of the ramp as well as the angle of the wheel, we can calculate both the displacement of the wheel as well as the angle of the ramp. Because we know the angle of the wheel relative to the ramp (indicated as "measured angle", m), and we know the angle of the ramp (indicated as β), using as we can obtain the relationship of "$m = \alpha + \beta$", which allows us to solve for the angular displacement of the wheel as $\alpha = m - \beta$. Using the angular displacement of the wheel makes it able to calculate the actual displacement of the wheel up the bank, $\Delta\vec{x} = r\left(\frac{\pi\alpha}{180}\right)$, where r is the radius of the wheels. Using the value of β allows us to find the distance of the barge to the wheel using trigonometry, specifically $d = l\cos\left(\frac{\pi\beta}{180}\right)$, where l is the length of each ramp.

3.3 Bow Thrusters

As the river level changes and the ramps move from their horizontal position, the application will automatically activate fore and aft bow thrusters to maintain the distance from dock to shore, thereby returning the ramp to their horizontal positions. Bow thrusters are a propulsion device built into or mounted on the ship's bow or stern to make it more maneuverable. They provide lateral thrust that can turn/move the bow or stern in either direction. Installed perpendicular to the centerline of the dock, the electrically powered thrusters use suction to draw in water from one side and push it out the other side to move the vessel in the opposite direction. Inclusion of these bow thrusters in our design was inspired by the crew of the American Countess, a pleasure cruise ship that effortlessly moored on the riverfront near the dock during our visit. Our plan includes installation of two bow thrusters, mounted on the existing substructure of the dock, one fore and one aft. The crew recommended two 26-inch commercial grade bow thrusters (225-hp) for our application. Research indicates that the bow thrusters will cost roughly $70,000 to purchase and install. The application will monitor and control the thrusters independently, while allowing the user to override and adjust speed.

Although expensive, we decided that this control mechanism was more robust than a simple microprocessor-based system to control the winches. When we took our tour, we watched the captain, with over thirty years of experience, as he slowly released and tightened cables to get the dock to the correct spot manually. It was an impressive display of skill, knowing when and how much give and take on each of the winches. We determined that a control algorithm would be nearly impossible to code given the complexity of the cable system and the unpredictable nature of the river. In fact, during our visit, we noticed a large log had been caught in the current and had been pinned against one of the submerged cables. Anomalies such as this could prove catastrophic to a control algorithm and drove our decision to a solution that focused as much on monitoring as control.

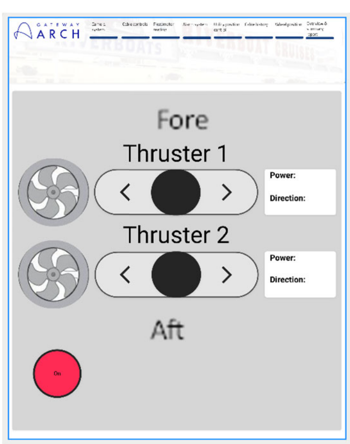

Figure: Bow thruster page

3.4 Cable controls

We are going to keep the same number and configuration of cables and winches that currently exist. The control app algorithm that controls the bow thrusters will then adjust the winches, using an 8085-microprocessor installed in the control box and connected wirelessly to the app, to account for the changes in the dock's location. If the thrusters push the dock toward the shore, the winches will take in slack cable, and will release cable when the dock is pushed away from shore. The cable subsystem will include a Greenlee 37179 Force Gauge Unit on each cable to monitor the tension. Each cable will have a set of normal tension ranges, set by the user, and each cable will automatically adjust to keep the tension in that equilibrium. In addition to monitoring the tension in each cable, the user will be able to override at any time via the app. In the case of a drastic shift in tension, such as a cable breaking or a tree falling on the cable, the app will trigger an alert.

In the current configuration, during extremely low river levels, the crew must manually move the connection point on the shore mounted chain hardpoints. To solve this problem, our proposal includes replacing the current 1-inch steel cables with new cables made of Kevlar. Since Kevlar is much stronger than steel, the required tensile strength of the cable can be met with a thinner cable. The current diameter of the largest carbon steel cable is one inch and is rated at 17,600 lbs tensile strength. With the Spectra 12 Strand cable made of Kevlar, we can reduce the diameter to one half of an inch, which is rated at 22,500 lbs. With this reduced diameter, we can fit more cable in the current spools, eliminating the need for the chain that currently must be manually adjusted for extreme situations. Specifications for steel and Kevlar cable can be found in the appendix.

The cost of the Kevlar cable would be approximately $2700 per 600 feet (estimated 1200 feet would be needed) as indicated below. The cost of the 8085 microprocessor will be approximately $160 and would take an estimated $5000 to install and connect to the app. Each industrial grade tension force gauge is $1200, and 5 will be needed. There would be an additional cost to develop the interface to the app (approximately $4000). Total cost for this subsystem would be around $20,000.

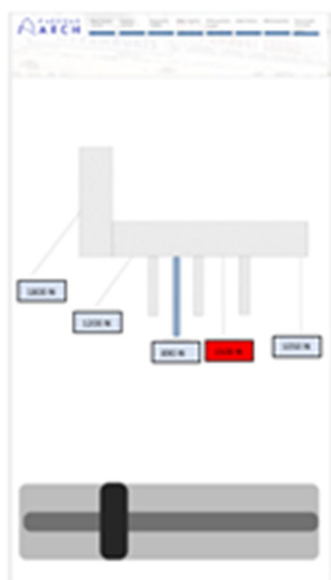

Figure: Cable tensions page. In this example, the third cable is selected for user override using the slider, and the 4th cable indicates a tension that is out of range and would be alerted.

3.5 Utility Deck

One of the main issues/constraints we faced when beginning to form our solution to the proposed problem was the utility line situation. There are 5 lines: a gas line, two water lines, a power line, and one phone line. These lines run from the shore to the dock. Currently, they are all tangled. When the river level rises, there is slack in the lines, and when it drops, the lines are pulled tight. When there is slack, the lines have to be manually moved. This is a major problem because it limits the possibility of making an automated system. To make everything much simpler, we propose combining the various lines into one large master utility line, which would consist of all the lines stacked vertically and then bound together. This configuration would allow maximum flexibility for the master line. To achieve an automated system, the solution needs to not only extend the line when additional length is needed, but manage the slack introduced when the dock moves closer to the shore. Our solution implements a double winch system, which would work in concert to pull on the cable stack when slack is introduced and allow the cable to play out when additional line is needed. The winches would pull the line into an S-shape when excess line is present as shown in the drawing below. This system would be placed on a utility deck placed under the main ramp. This deck would expand beyond the width of the ramp to accommodate the winch system. This will allow the S curve to be larger, lessening the “tightness” of the curve. This deck would be made of metal grate to allow the water to be able to pass through it in case of submersion. In this case, the winches must be water-proofed as well. Another advantage of this utility deck is future maintenance. There could be a ladder along the side of the ramp leading down to the deck. This will allow easy access, and easy maintenance if there were to ever be a problem with the system. The app will monitor the status of the winches. As an option, flow meters could be installed on each utility line with data fed to the app to ensure line integrity.

This subsystem is a custom installation and would involve different utility companies, various fittings, changes to the existing ramp, two winches, and control integration to the main app. Although it is difficult to guarantee costs on a project such as this, an estimate was provided by our mentor based on past experience. This estimate is placed at 300 man-hours at $80 per hour, plus $10,000 for winches and miscellaneous hardware for a total of approximately $24,000.

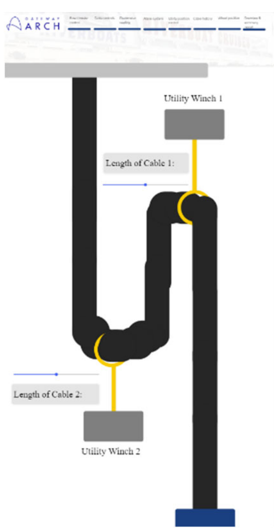

Figure: Utility line page

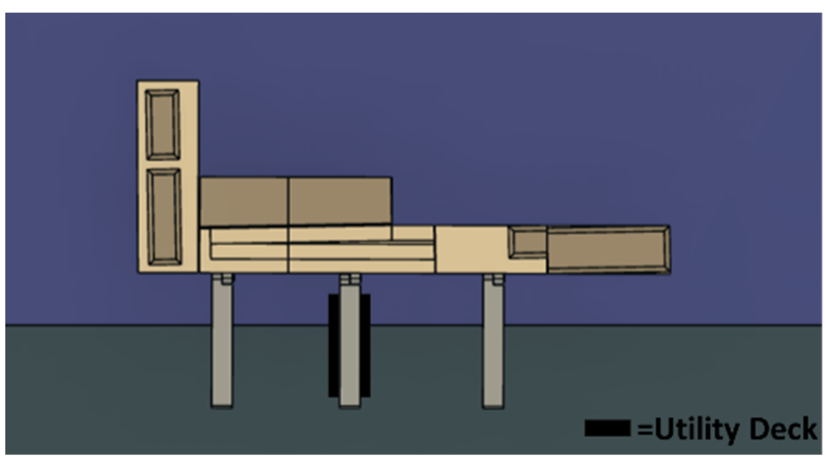

Figure: Utility deck shown under the middle ramp

3.6 Camera Monitoring

Although our system will provide alerts for system anomalies as discussed above, the complexity of the system and the unpredictable nature of the river demands acute situational awareness. To provide the user with the maximum amount of real-time information, our solution will integrate a camera monitoring system. We will install a set of CCTV cameras with remote viewing. This will allow the user to see everything that is happening at the dock directly from the app and will allow visual assessment of the seriousness of each alert that the system provides. Each view will be visible from the app, and each camera will be recording until the storage is full in which case the oldest recorded data will be deleted and new recordings will be saved. Within the app you will be able to zoom in and rotate the camera to get a better view of any situation. This will help ensure that nothing is going wrong with the automated system and will help with the dock's safety. This system would cost around $1,200 plus installation.

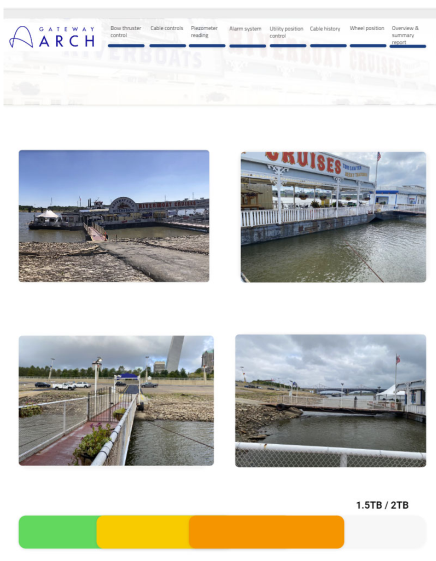

Figure: video surveillance page

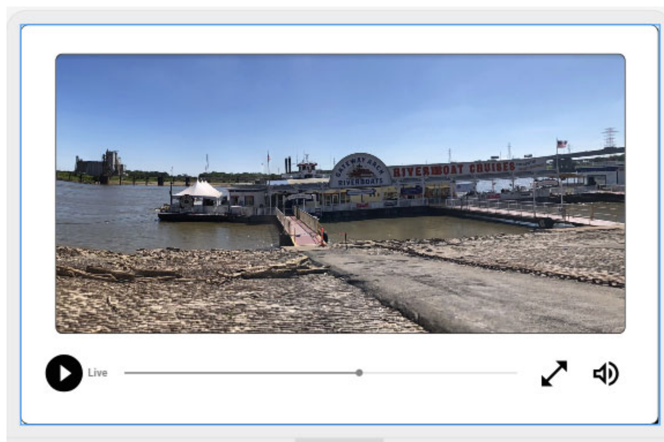

Figure: individual camera control page

4. Summary

As history has shown, the Mississippi River is unpredictable yet extremely powerful. River levels can change rapidly and range from incredible lows to unimaginable highs. Currents in the river can be complicated and routinely carry large amounts of sizable driftwood and other debris. In the winter, ice floes can attach to the dock or flow with the current. In other words, this is a complicated problem. And often, complicated problems require complicated solutions. By integrating various subsystems through a centralized web application, the complicated solution is simplified through an intuitive system of monitoring, control, and alerting. The app monitors situational awareness of the barge by monitoring and comparing location of the barge relative to the shore, existing river conditions, angle of the ramps, mooring cable tensions, bow thruster status, and utility line integrity. Even with all of these feedback loops and cross checks in the autonomous system, the possibility of error conditions loom. These conditions can be identified and isolated by the system. By integrating camera feeds and providing manual override of the subsystems, these error conditions can be dealt with by the operator remotely. The software system could even include machine learning algorithms or Kalman filters on the data to improve the solutions over time.

Of course, complicated solutions are not inexpensive. There are many different subsystems in our solution that each have their own cost. These costs come from the MCA application ($35,000) which controls the autonomous solution and provides the user interface for monitoring, control and alerting, a ramp monitoring system ($7,500), cables and control of cables ($20,000), bow thrusters ($70,000), a utility deck and line-control system ($24,000), and camera monitoring system ($1,500). All of these costs add up to around $160,000. This is a rough estimation mainly because the complexity of the software and unknown labor costs make the cost hard to predict. Our estimates for these costs are based on similar applications we have scoped in prior projects, as well as input from our civil engineer consultant and IT professionals.

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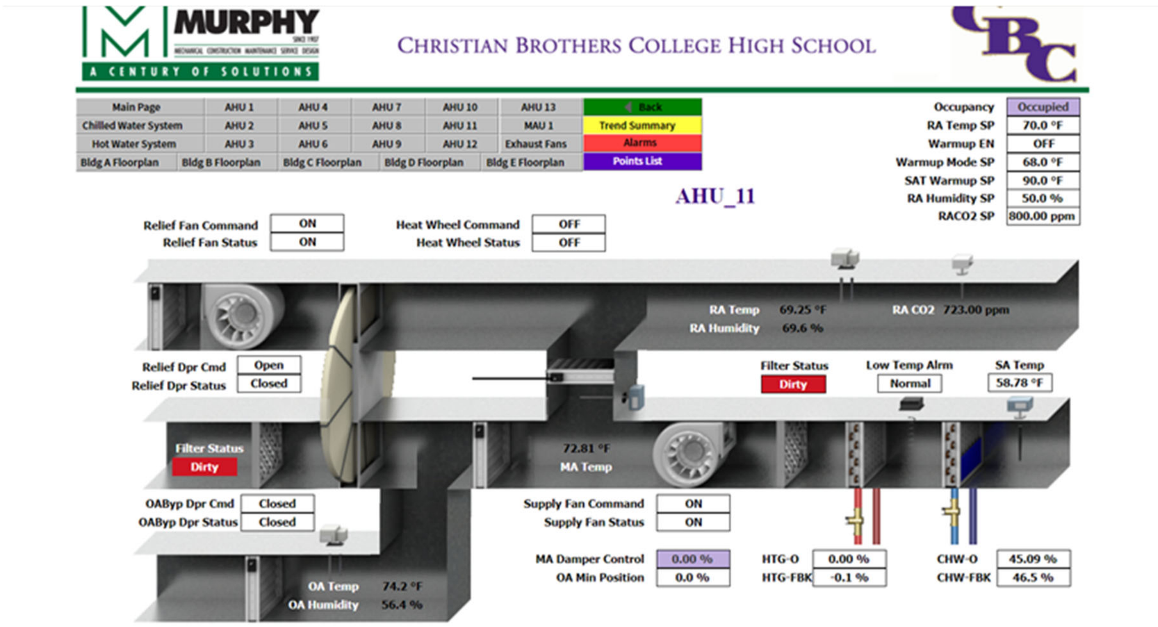
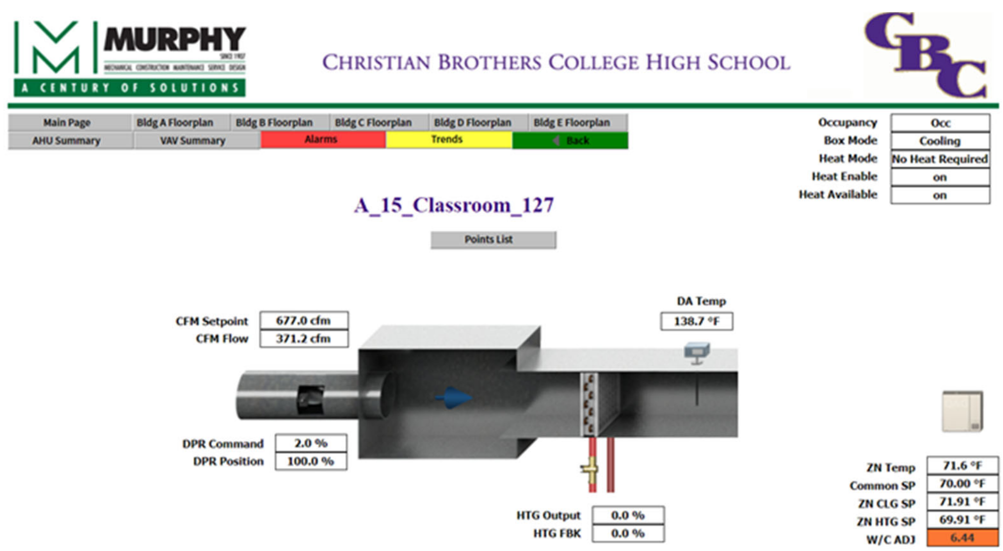
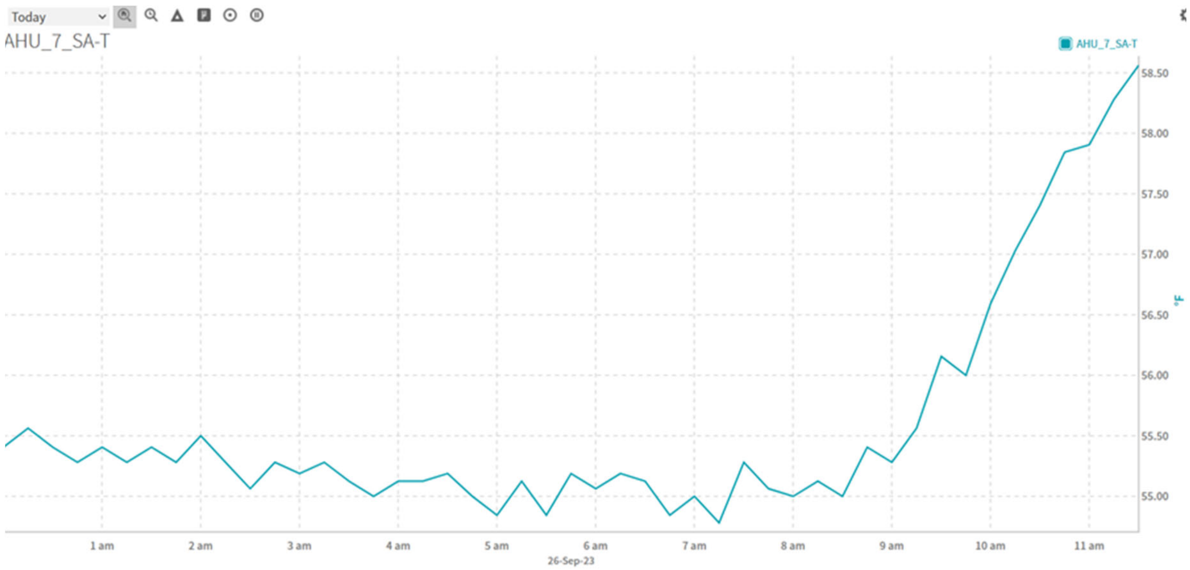
Appendix

The following images are screenshots of the actual CBC monitor, control and alert app for the HVAC system.





A graph showing the fluctuating average temperature in the building.



A table showing the current temperature for each room in the building.

MURPHY

A CENTURY OF SOLUTIONS

CHRISTIAN BROTHERS COLLEGE HIGH SCHOOL

Chilled Water System	AHU 1	AHU 4	AHU 7	AHU 10	AHU 13	AHU Summary	
Cooling Towers	AHU 2	AHU 5	AHU 8	AHU 11	MAU 1	VAV Summary	
Hot Water System	AHU 3	AHU 6	AHU 9	AHU 12	Exhaust Fans	MechRM EXFans	
Bldg A Floorplan	Bldg B Floorplan		Bldg C Floorplan		Bldg D Floorplan	Bldg E Floorplan	

Back | Main Page | Override Summary | Trend Summary | Alarms

VAV Summary BldgA 2ndFl | VAV Summary Bldg B | VAV Summary Bldg C | VAV Summary Bldg D | VAV Summary Bldg E

VAV	ZN Temp	ZN SPT	DAT	CFM FlOW	CFM SPT
A_1_Classroom_120	71.2 °F	70.00 °F	59.0 °F	753.8 cfm	735.0 cfm
A_2_Classroom_117	72.7 °F	70.00 °F		79.1 cfm	500.0 cfm
A_3_Classroom_122	73.9 °F	70.00 °F	71.9 °F	0.0 cfm	735.0 cfm
A_4_Classroom_123	70.2 °F	70.00 °F		0.0 cfm	495.0 cfm
A_5_1stFl_NW_Corridor	71.5 °F	70.00 °F		0.0 cfm	150.0 cfm
A_6_Classroom_124	72.3 °F	70.00 °F		303.3 cfm	750.0 cfm
A_7_Nurses_Office_RM32	70.5 °F	70.00 °F		88.3 cfm	75.0 cfm
A_8_Business_Lobby_RM10	73.3 °F	70.00 °F	89.9 °F	0.0 cfm	275.0 cfm
A_9_Business_Office	71.7 °F	70.00 °F		0.0 cfm	100.0 cfm
A_10_1stFl_NE_Corridor	71.4 °F	70.00 °F		689.2 cfm	700.0 cfm
A_11_1stFl_RestRms	76.8 °F	70.00 °F	100.8 °F	54.9 cfm	540.0 cfm
A_12_Copy_MailRM	72.8 °F	70.00 °F		70.6 cfm	495.0 cfm
A_13_Classroom_126	71.4 °F	70.00 °F	71.3 °F	317.0 cfm	495.0 cfm
A_14_Classroom_107	72.0 °F	70.00 °F		0.0 cfm	0.0 cfm
A_15_Classroom_127	71.6 °F	70.00 °F	138.8 °F	374.3 cfm	692.4 cfm
A_16_Classroom_128	73.0 °F	70.00 °F		0.0 cfm	735.0 cfm
A_17_Classroom_130	73.5 °F	70.00 °F	130.0 °F	717.4 cfm	735.0 cfm
A_18_Classroom_101	71.4 °F	70.00 °F		0.0 cfm	900.0 cfm
A_19_Classroom_103	71.6 °F	70.00 °F	60.0 °F	0.0 cfm	495.0 cfm

VAV	ZN Temp	ZN SPT	DAT	CFM FlOW	CFM SPT
A_20_Classroom_102	72.4 °F	70.00 °F		102.1 cfm	1200.0 cfm
A_21_Classroom_104	71.4 °F	70.00 °F		63.9 cfm	0.0 cfm
A_22_Classroom_105	73.7 °F	70.00 °F	63.0 °F	230.2 cfm	900.0 cfm
A_23_Classroom_106	74.4 °F	70.00 °F		44.4 cfm	900.0 cfm
A_24_Classroom_108	73.5 °F	70.00 °F	59.3 °F	0.0 cfm	900.0 cfm
A_25_Classroom_109	71.0 °F	70.00 °F		0.0 cfm	495.0 cfm
A_26_Classroom_110	70.8 °F	72.00 °F	57.49 °F	311.08 cfm	1000.0 cfm
A_27_1stFl_SE_Corridor	71.2 °F	70.00 °F		656.4 cfm	657.3 cfm
A_28_Classroom_111	73.0 °F	70.00 °F	58.7 °F	476.1 cfm	900.0 cfm
A_29_1stFl_S.Central_Corridor	71.0 °F	70.00 °F		0.0 cfm	560.0 cfm
A_30_Classroom_112	73.7 °F	70.00 °F	58.6 °F	0.0 cfm	600.0 cfm
A_31_Classroom_114	73.6 °F	70.00 °F		193.7 cfm	900.0 cfm
A_32_1stFl_SW_Corridor	71.4 °F	70.00 °F		156.4 cfm	148.6 cfm
A_33_Classroom_113	69.2 °F	70.00 °F		1210.7 cfm	1200.0 cfm
A_34_Classroom_115	72.5 °F	70.00 °F	59.7 °F	0.0 cfm	495.0 cfm
A_35_Classroom_116	72.7 °F	70.00 °F		0.0 cfm	495.0 cfm
A_36_Classroom_118	73.1 °F	70.00 °F	58.3 °F	380.0 cfm	900.0 cfm
A_37_Classroom_119	72.5 °F	70.00 °F		703.8 cfm	900.0 cfm
A_38_1stFl_N.Central_Corridor	71.7 °F	70.00 °F		0.0 cfm	400.0 cfm

A chart of the Kevlar cable by diameter, and the load it can carry.

- Very Low stretch
- Very High strength
- Soft hand
- Torque free
- Easy splicing
- Floats

Type Approved Product

	Nominal Diameter		CSI Ref. #	Size Number (circ)	Approximate Weight		Minimum Tensile Strength	
	in.	mm			lbs/100ft	Kg/100m	Pounds	kN
	7/64	2.5	CS-06-0820	5/16	0.33	0.5	1,125	5
	1/8	3	CS-06-0821	3/8	0.53	0.8	1,800	8
12 Strand	3/16	5	CS-06-0822	9/16	1	1.5	3,600	16
	1/4	6	CS-06-0823	3/4	1.6	2.4	6,000	26.7
	5/16	8	CS-06-0824	15/16	2.6	3.9	9,000	40
			ABS and DNV Type Approved Sizes					
	3/8	9	CS-06-0825	1-1/8	3.7	5.5	13,900	61.8
	7/16	11	CS-06-0826	1-1/4	4.2	6.3	14,800	65.8
	1/2	12	CS-06-0827	1-1/2	6.4	9.5	22,500	100.1
	9/16	14	CS-06-0828	1-3/4	7.9	11.8	27,700	123.2
	5/8	16	CS-06-0829	2	10.6	15.8	36,600	162.8
	3/4	18	CS-06-0830	2-1/4	13.3	19.8	43,200	192.2

A graph showing what steel cables can hold by diameter.

Wire Ropes - Strengths							
Rope Diameter		Minimum Breaking Strength		Safe Load		Weight	
(in)	(mm)	(lb_f)	(kN)	(lb_f)	(kN)	(lb_m/ft)	(kg/m)
1/4	6.4	5480	24,4	1100	4.89	0.11	0.16
5/16	8	8520	37,9	1700	7.56	0.16	0.24
3/8	9.5	12200	54,3	2440	10.9	0.24	0.36
7/16	11.5	16540	73,6	3310	14.7	0.32	0.48
1/2	13	21400	95,2	4280	19.0	0.42	0.63
9/16	14.5	27000	120	5400	24.0	0.53	0.79
5/8	16	33400	149	6680	29.7	0.66	0.98
3/4	19	47600	212	9520	42.3	0.95	1.41
7/8	22	64400	286	12900	57.4	1.29	1.92
1	26	83600	372	16700	74.3	1.68	2.50
1 1/8	29	105200	468	21000	93.4	2.13	3.17
1 1/4	32	129200	575	25800	115	2.63	3.91
1 3/8	35	155400	691	31100	138	3.18	4.73
1 1/2	38	184000	818	36800	164	3.78	5.63