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Technical Search and Rescue Camera Rotation Circuit Segment Redesign Process Study

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Abstract

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Savox Communications underwent a technical review for their SearchCam 3000 product that included the possibility of redesigning the product's schematics in a way that excluded a difficult-to-source component without altering the circuit's functionality.

The component and its associated circuit segment are responsible for the camera's rotation, which is defined by user input. This thesis will focus on describing the theory and processes required for considering this redesign, and on whether such a redesign is possible within the constraints of the existing schematics and available materials. The purpose of this work lies in detailing the process which most redesigns must undergo.

There will be a focus in outlining the practical and theoretical challenges that may arise in a redesign of a previously established product.

Keywords: motor control, camera rotation, PID, reverse engineering, component management, redesign

Contents

List of Abbreviations

ADC: Analog to Digital conversion. Conversion of an analog signal to a corresponding digital value.

BOM: Bill of Materials. List of components, parts and other related items with their respective detailed information that is consulted for manufacturing.

CMOS: Complementary mode MOSFET. A combination of NMOS and PMOS.

DC: Direct Current. Current that flows in only one direction.

EOL: End-of-Life. Process that indicates final operations are underway with a product's lifecycle.

FET: Field Effect Transistor. Transistor. FETs control the flow of current through an electric field.

I^2C: Inter-Integrated Circuit. Bus interface connection protocol used for synchronous serial communication.

ISR: Interrupt Service Routine. Interrupt handler, block of code responsible for interrupting a process, as initiated by hardware or software instructions or exceptions.

JTAG: Joint Test Action Group. Industry standard used for the testing, debugging and programming of on-chip instrumentation.

NRND: Not Recommended For New Designs.

MOSFET: Metal Oxide Semiconductor Field Effect Transistor. A subtype of FET, usually made via the controlled oxidation of silicon.

NMOS: N-Channel MOSFET.

N-Type: N-Type/N-Channel, extrinsic semiconductors. Semiconductors that are doped to have negative electrons as their majority carrier.

PID: Proportional-Integral-Derivative controller. Continuous, modulated control loop mechanism.

PMOS: P-Channel MOSFET.

P-Type: P-Type/P-Channel, extrinsic semiconductors. Semiconductors that are doped to have electron acceptor atoms (positive holes) as their majority carrier.

PWM: Pulse Width Modulation. Digital signal fed in pulses (switched ON and OFF at intervals), used to regulate output power.

SPI: Serial Peripheral Interface. Synchronous serial communication standard for most embedded systems when it comes to short distance wired communication between integrated circuits.

VDU: Video Display Unit.

TTL: Transistor-Transistor Logic. Relatively inexpensive and static electricity discharge resistant circuit logic with high current consumption that creates switching and logic states with bipolar transistors.

TVS diode: Transient Voltage Suppression diode. TVS diodes suppress all over voltages that go above their designated breakdown voltages.

UART: Universal Asynchronous receiver-transmitter. Bus interface connection used for asynchronous serial communication.

USART: Universal Synchronous and Asynchronous receiver-transmitter.

1 Introduction

Savox Communications designs and manufactures rugged communication and hearing protection solutions for public safety and security and military use worldwide.

The SearchCam 3000 was designed to locate victims trapped in collapsed buildings, under water inspections, and other similar situations. Its articulating, waterproof camera head with LED lighting helps pinpoint the victim's location so rescuers can extract them. On-screen graphics help direct rescue teams to victim locations to begin extraction and two-way audio allows rescuers to communicate directly with victims. Rescuers can record audio and video, as well as take still photos during the search through the SearchCam. [1.]

Internal reviews were carried out at Savox for the aforementioned product so that it could be kept up to date and available for purchase. It was observed that one of the components required for the construction of the SearchCam 3000 was approaching End-Of-Life: this implied that there was a need to source a new, equivalent component that was still being actively manufactured and supported.

The process of finding a component that performs in the same manner as the original can be difficult and is sometimes impossible. Taking this into account, the hardware team at Savox looked at the possibility of a circuit redesign where this component could be phased out. The component in question is a potentiometer, which is used to direct the DC motor that drives the 240° rotation of the

SearchCam 3000's camera, whose body and camera rotation can be seen in figures 1 and 2, shown below.

Figures 1 and 2. Depiction of the entire SearchCam 3000 and closeup of its camera's 240° rotation capabilities [1].

This thesis has the goal of detailing the process of investigating the possibility of a circuit redesign and whether it has a possible subsequent implementation or not. The goal is to provide insight on the details of what most redesign processes entail. Research on available, product specific documentation and other information related to various aspects of this product's circuit design and behavior will be conducted and documented for the purposes of this proposed redesign.

2 Theoretical Background

This section will provide information on the individual components, circuit and part logic and concepts that were required to consider the implementation of the design study outlined further ahead. Without this background knowledge, it would not be possible to deign a redesign feasible, as there would potentially be too many unknown elements in the circuit that was to be evaluated for there to be a consensus on whether changes would affect other functionalities or not.

2.1 Potentiometer

A potentiometer is a passive component with three terminals. It has a sliding or rotating contact that can be moved along the resistor on the output terminal while the two other terminals are fixed to the input. The potentiometer's final output voltage is the voltage drop between the fixed inputs and the moving output contact. This configuration can be seen below in Figure 3.

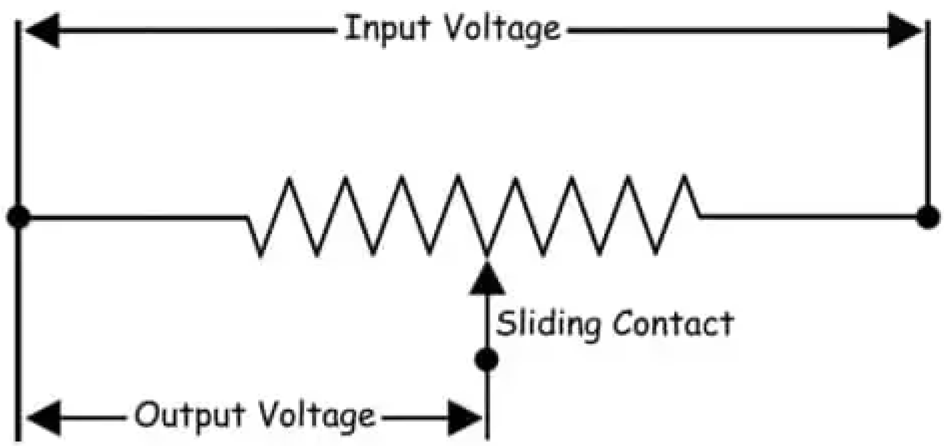


Figure 3. Adjustable Voltage Divider Configuration for a Potentiometer [2].

A potentiometer can also be used as a resistor or as a rheostat, controlling the amount of current that flows through a circuit via the adjusting of resistance when it is configured with only two of its terminals (with one of these terminals acting as a wiper) [2;3]. Figure 4, below, depicts a rheostat's circuit.

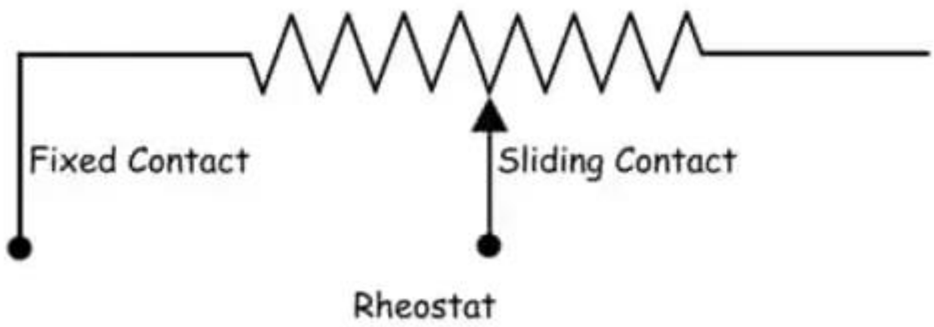


Figure 4. Resistor/Rheostat Configuration for a Potentiometer [2].

The SearchCam 3000´s potentiometer was a 6909 series, 5kΩ, +-10% tolerance potentiometer from *Spectrum Sensors & Controls Inc*. It supported up to an electrical angle of 350° and its mechanical knob was of a rotary, continuous design. Its outer element had a diameter of around 1.79cm. [4.]

Savox was able to find a replacement potentiometer to the one that has become obsolete, with similar dimensions and electrical/mechanical specifications; this new component is, however, liable to reach EOL soon and is rather bulky and costly to obtain for what it does, which is why there is an interest in researching whether this element can be excluded entirely from the product’s design.

2.2 Voltage Divider

A voltage divider circuit is used to produce an output voltage that is a fraction of the input. The output voltage is commonly utilized as a reference for other devices, such as voltage comparators. SearchCam 3000 schematics have many instances where voltage division is applied, as do most elaborate circuit schematics. The voltage divider is highlighted here, however, because it is the method by which the potentiometer is able to adjust the voltage to rotate the SearchCam’s camera as desired by the user. It is, therefore, a circuit element that must be recreated in the hypothetical redesign.

The voltage is divided across components Z_1 and Z_2 in Figure 5, shown below. The current at the output is assumed to be zero.

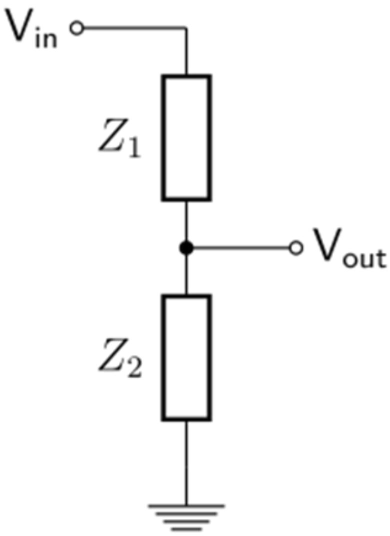


Figure 5. Resistive Voltage Divider Circuit [5].

Applying Ohm's Law at the input in equation (1) and at the output in equation (2) will derive equation (3):

$$V = I \cdot (Z_1 + Z_2) \quad (1)$$

$$V_{out} = I \cdot Z_2 \quad (2)$$

$$V = V_{out} / Z_2 \cdot (Z_1 + Z_2) = V_{out} = Z_2 / Z_1 + Z_2 \cdot V \quad (3)$$

According to equation (3), the output voltage is dependent on the impedance and on the input voltage. Adjusting these constrains will lead to the desired voltage.

2.3 Flyback Diodes

Flyback diodes are used to prevent voltage spikes across inductive loads when the supply current is suddenly cut off or reduced.

According to Faraday's Law of Induction, a changing magnetic field induces a voltage in a circuit. If the current changes through an induction, it will induce a voltage to find a path for the current to flow. In the context of a switching circuit, flyback diodes are there as a bridge that will help carry and lower the voltage as it travels from one switch to the other [6; 7].

In an H-Bridge circuit with no flyback diodes where both the switches are suddenly turned off on one side, the voltage can get high enough to be conducted through the air as it attempts to get the current to reach the next component.

In a circuit with mechanical switches, this will be observed in the form of a sudden arc across the circuit's contacts. This momentary dissipation of energy will either immediately or eventually damage these contacts and render the switches useless if it is not addressed.

In a circuit with non-mechanical solid-state switching, as is the case of the SearchCam 3000's H-Bridge circuit (which uses power MOSFETs as switches), the sudden high voltage dropped across inactivated switches would likely damage them, had they no flyback diodes implemented.

Schottky diodes are generally preferred as flyback diodes due to their low forward drop (less voltage will enter the next component compared to other diodes) and their ability to react quickly to reverse bias (when the corresponding inductor is re-energized). This results in less energy being dissipated if there is a transfer of it from an inductor to a capacitor. [7.]

2.4 MOSFETs

A Metal Oxide Semiconductor Field Effect Transistor is a subtype of the Field Effect Transistor (FET), and it is commonly built via the controlled oxidation of silicon. MOSFETs can also be called a IGFETs (Insulated Gate Field Effect Transistors) or MISFETs (Metal Insulator Semiconductor Field Effect Transistors). The MOSFET is the most common transistor used in digital circuits and it can be built with either p-type or n-type semiconductors. [8.]

The voltage applied at the insulated gate of the MOSFET may increase the conductivity of the device (enhancement mode MOSFET) or decrease it (depletion mode MOSFET) depending on whether positive or negative voltage is applied, respectively. This insulation at the gate makes it so that the MOSFET has a very high input resistance. Enhancement mode MOSFETs are equivalent to ‘normally open’ switches while depletion mode MOSFETs are equivalent to ‘normally closed’ switches.

Figure 6 shows diagrams for both types of MOSFETS. The ‘substrate’ terminal is grounded; it is usually internally connected to the ‘source’ terminal in discrete type MOSFETs and omitted for clarity.

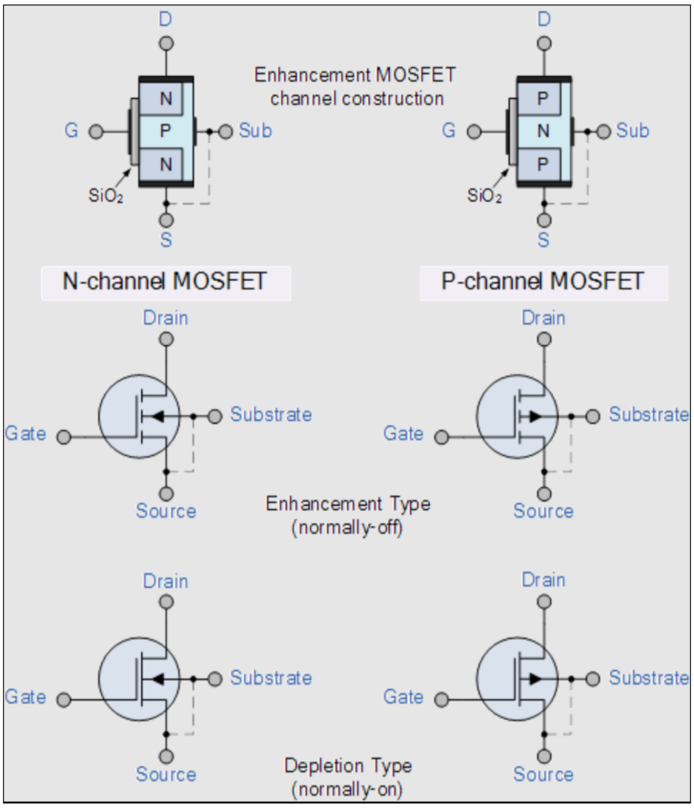


Figure 6. N-channel and P-channel MOSFET (NMOS and PMOS) structure [9].

The current flowing between the MOSFET’s ‘drain’ and ‘source’ terminals is proportional to the applied voltage and there should be no current flowing to the ‘gate’ terminal, as it is insulated.

A NMOS forms a closed circuit when receiving non-negligible voltage and an open circuit otherwise (when the voltage applied is less or equal to 0V). A PMOS works in reverse, meaning that it has an open circuit when it receives non-negligible voltage and is closed otherwise.

The MOSFETs used for the SearchCam 3000's motor driving circuit are in an integrated chip (SI9988), in a combination of enhancement mode PMOS and NMOS that form a CMOS logic gate when designed together. These are the transistors that form the SI9988's H-Bridge, which is described in the following section (2.5). CMOS is usually preferred to TTL when designing low current circuits.

2.5 H-Bridge

A H-Bridge circuit is a configuration that allows for a switch in the polarity of the voltage that is applied to the load. The H-Bridge is used in most converters and motor drivers. It will be used in this circuit to drive the DC motor responsible for rotating the camera of the SearchCam 3000.

The H-Bridge has its name derived from the placement of the four switches that comprise it: they roughly form an 'H' in the circuit, as can be seen from figure 7, shown below:

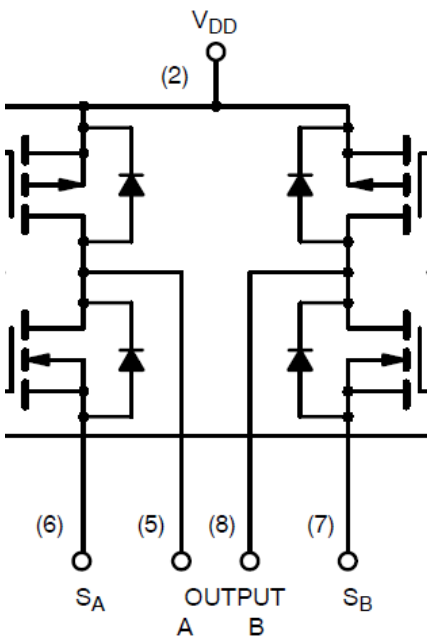


Figure 7. Excerpt of the Si9988's H-Bridge circuit block diagram with a pair of PMOS and a pair of NMOS acting as the switching elements and their respective flyback diodes (image taken from Vishay's Si9988DQ-T1-E3 datasheet [10]).

An H-Bridge's basic operating mode will have the top left and bottom right transistors of Figure 7 turned ON (closed switches) while the top right and bottom left transistors are turned OFF (open switches) for the left lead of the motor to be connected to the power supply and for the right lead to be connected to ground, thus driving the motor shaft to rotate one way.

The H-Bridge will turn the top left and bottom right transistors OFF (open switches) and the top right and bottom left ON (closed switches) for the right lead of the motor to be connected to the power supply and for the left lead to be connected to ground, driving the motor shaft to rotate the opposite way.

Figure 8 illustrates the operation in a simplified diagram:

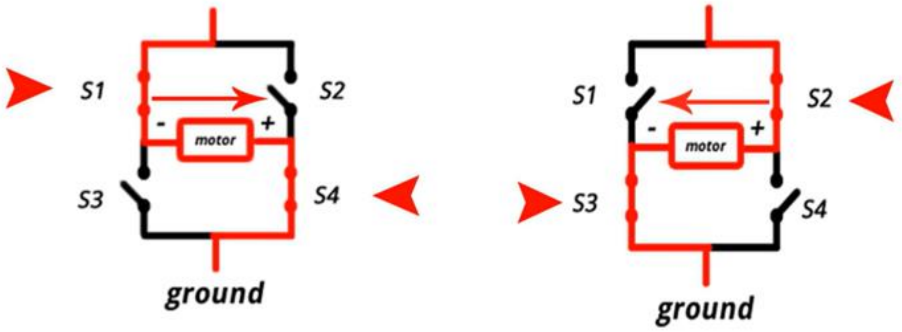


Figure 8. Basic operation of a H-Bridge circuit [10].

2.6 Brushed DC Electric Motor

In a brushed DC motor, DC current will turn the coil windings around the rotor of the motor into an electromagnet that acts against the force of the stator magnets' electromagnetic field, causing the rotor to turn. This rotation will bring the commutator segments to meet their opposite brushes, hence switching the polarity of the coil windings. The rotor, which was originally approaching a magnet that attracted it, is suddenly repelled. This maintains rotation as it happens repeatedly.

The smoothness of this rotation process tends to increase with an added number of coil windings and commutators to the rotor. Reverse voltage spikes occur whenever a brush meets a gap between commutators, which can cause electrical noise that may damage sensitive electronics that are connected to the same voltage source. This problem can be counteracted by the addition of TVS diodes.

The process of causing the motor to break immediately without a gradual decrease in rotation involves shorting the motor leads together; this is called dynamic breaking. If a motor is connected to a load that carries a lot of momentum, dynamic breaking can cause it to get excessively hot, possibly burning the windings: placing a large wattage resistor in series helps eliminate this problem [11; 12; 13]. An illustration of a brushed DC motor can be seen in figure 9, shown below.

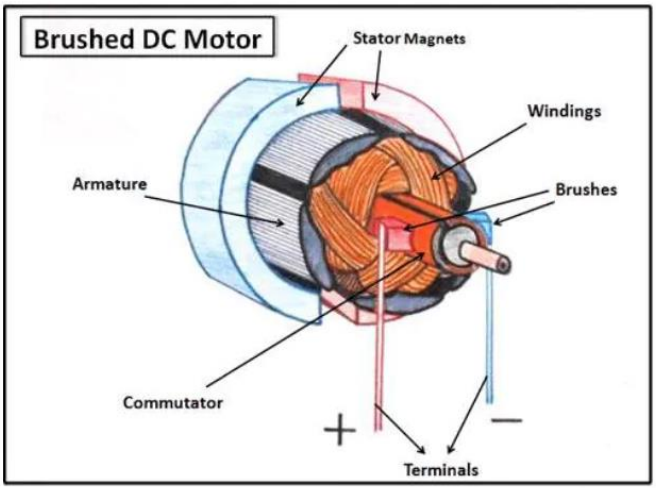


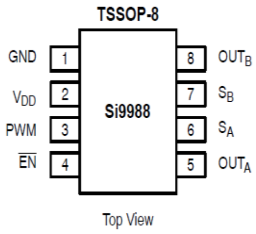
Figure 9. Brushed DC Motor [12].

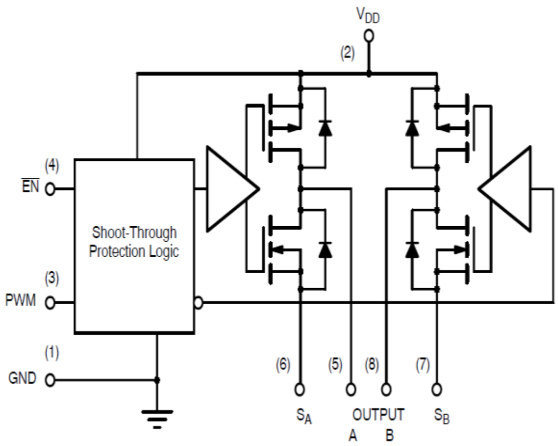
2.7 Brief Description of the SI9988's Functionality

According to the SI9988 datasheet [14]:

The SI9988 is an integrated, buffered H-bridge with TTL compatible inputs and the capability of delivering a continuous 0.65 A @ VDD = 5 V (room temperature) at switching rates up to 200 kHz. Internal logic prevents the upper and lower outputs of either half-bridge from being turned on simultaneously (…). [14.]

The SI9988 is suitable for driving DC brushed motors. The datasheet [14] provides its pin configuration, block diagram and truth table, as seen in Figure 10, shown below:





TRUTH TABLE			
$\overline{EN}$	PWM	OUT_A	OUT_B
0	0	0	1
0	1	1	0
1	0	0	0
1	1	0	0

Figure 10. Pin configuration and truth table for the SI9988 Buffered H-Bridge [14].

The SI9988 is an inexpensive, premade integrated circuit which provides an H-Bridge driver. Using the SI9988 may prevent short circuits that could otherwise arise from manually building a motor driving circuit out of discrete components.

2.8 Brief Description of the MSP430F1611's Functionality

The Texas Instruments MSP430 family of ultralow power microcontrollers consist of several devices featuring different sets of peripherals targeted for various applications. (…) The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6 µs. The MSP430F15x/16x/161x series are microcontroller configurations with two built-in 16-bit timers, a fast 12-bit A/D converter, dual 12-bit D/A converter, one or two universal serial synchronous/asynchronous communication interfaces (USART), I2C, DMA, and 48 I/O pins. (…) Typical applications include sensor systems, industrial control applications, hand-held meters, etc. [15.]

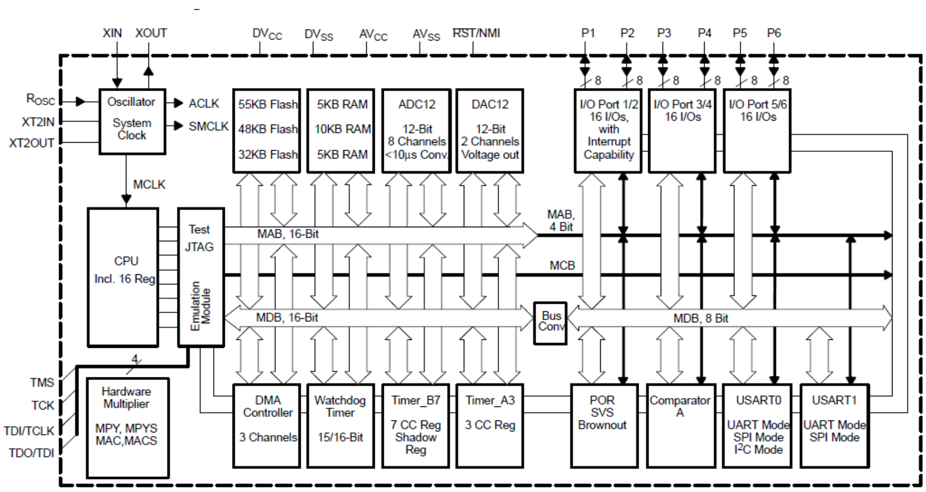


Figure 11. Block Diagram for the MSP430F161x series of microcontrollers [15].

The MSP430 series of microcontrollers is programmable through the FET-Pro430 flash programmer. A block diagram illustrating its functionality, taken from the MSP430F1611's datasheet, can be seen in Figure 11, seen above. The FET-Pro430 consists of a device with dedicated software that can program the MSP430s through a JTAG interface once it is connected to the microcontrollers' parallel or USB ports. [20.]

MSP430's datasheet seems to show that the microcontroller supports a variety of serial connection protocols and multiple I/O pins. These are the most important points to keep in mind in the context of a possible potentiometer replacement.

2.9 PID Controller

Proportional Integral Derivative control is a common control algorithm known for its functional simplicity and is universally accepted in industrial control systems due to its robust performance in a wide range of operations [16].

The source code for the SearchCam 3000 makes use of PID control logic for the purposes of controlling the speed and position of the DC motor that rotates the camera.

The goal of a PID controller is to read data, calculate and sum the three component responses (P, I and D) so that it may obtain the desired actuator output that drives the system. This is called a closed loop control system; the process of reading values to provide constant feedback and calculate the output is repeated continuously and at a fixed loop rate, as shown in Figure 12. [16.]

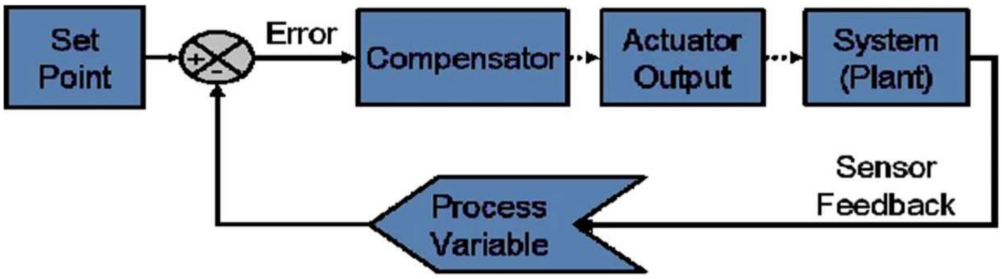


Figure 12. Block Diagram of a typical closed loop control system [16].

The process variable is usually the parameter that is controlled, position or temperature being examples of such parameters. A sensor is usually used to measure this variable and to provide feedback to the control. MSP430F1611 is what is performing the sensing in the case of the SearchCam 3000's PID control, by reading the value fed to it from the user and providing feedback in the form of a PWM signal to the motor driver.

The setpoint is the command value for the process variable. The difference between the process variable and the setpoint is repeatedly referenced by the compensator to determine the output that will drive the system. [16.]

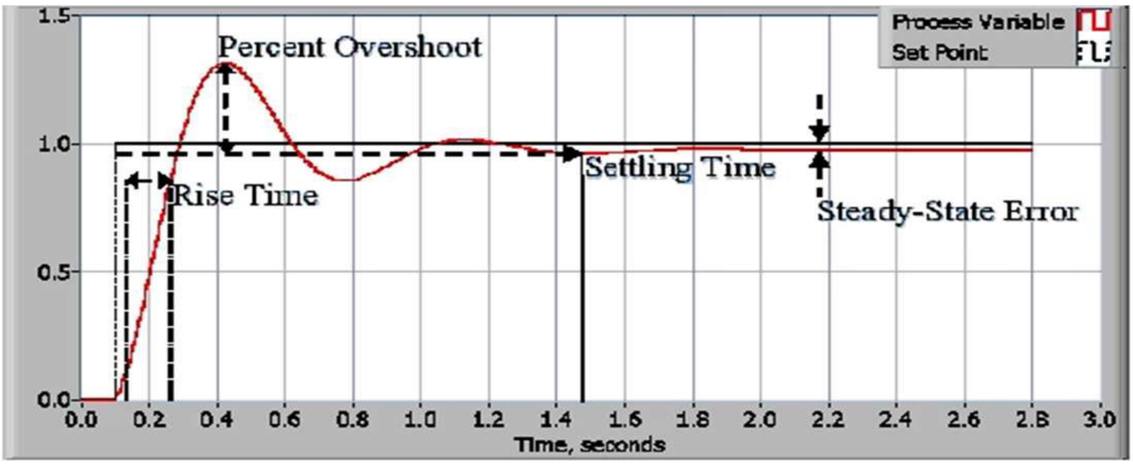
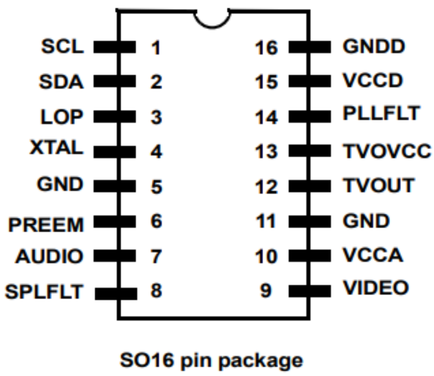


Figure 13. Example of the response of a PID closed loop control system [16].

The system's performance is measured by applying a step function as the setpoint command value, and by measuring the process variable's response, as shown in Figure 13. The rise time is in the figure represents the amount of time the system requires to go from a 10% to a 90% steady-state. The percentage overshoot is the amount by which the process variable overshoots the setpoint, and it is expressed as a percentage of that value. The settling time shows the time that the process requires for the variable to settle within a commonly expected 5% of the setpoint. The steady-state error is the final difference between the process variable and its command value. [16.]

2.10 Brief Description of the MC44BS374T1AEF's Functionality

MC44BS374T1AEF is an audio and video modulator with an integrated voltage-controlled oscillator. It makes use of I^2C for its read and write functions [22]. Its package and pin descriptions can be seen in Figures 14 and 15, shown below. MC44BS374T1AEF is used to modulate the audio and video signals put out by MSP430F1611 [17].



Pin number	Pin Name	Description
1	SCL	I2C clock
2	SDA	I2C data
3	LOP	Logical output port controlled by I2C bus
4	XTAL	Crystal
5	GND	Ground
6	PREEMP	Pre-emphasis capacitor
7	AUDIO	Audio input
8	SPLFLT	Sound PLL loop filter
9	VIDEO	Video input
10	VCCA	Main analog supply voltage
11	GND	Analog ground
12	TVOUT	TV output signal
13	TVOVCC	TV output stage supply voltage
14	PLLFLT	RF PLL loop filter
15	VCCD	Digital supply voltage
16	GNDD	Digital ground

Figures 14 and 15. Datasheet captions for the pin connections and descriptions of MC44BS374T1AEF [17].

This component overall does not seem to interface with the functionalities concerning the camera rotation motor. Additionally, the custom SearchCam 3000 VDU makes use of this component to provide video and audio display but seems to not concern itself with the camera rotation, as will be evidenced in further sections.

3 Component & EOL Management

An EOL check is usually done to all product parts during product reviews and circuit redesigns. Components that are found to have reached EOL or are NRND must be replaced by equivalent, available components so that production can continue. The process of researching and approving a new, equivalent component is an endeavor unto itself, so having these reviews often is preferred in order to avoid sudden stops in product availability.

The initial EOL check for the SearchCam 3000 consisted in investigating whether all components used in the schematic were available for purchase and had an active lifecycle.

3.1 Component Listing

The PCB BOM file for the SearchCam 3000 lists most components used for the product. There is some information loss relative to component manufacturer codes due to the irregular, manual version control of older schematics. The potentiometer to be excluded from the design was missing from the BOM, so information on it had to be searched for manually.

Below is a list of the main active components in use, with their manufacturer part codes:

Table 1. Partial EOL list for the SearchCam 3000.

TLE2426ID	IC VOL REF Series Adjustable 20.2V 20mA ±1% 8-SOIC Tube	Active
LT3431EFE#PBF	IC VOLT REG Adjustable Step-Down Buck 1OUT 1.2V - 60V 3A (Switch) 16-SOP Tube	Active
AG203-63G	RF Amplifier 6GHz 8dBm SOT-363 T/R	Active
MSP430F1611IRTDT	IC MCU 16Bit MSP430 FLASH 48kB (48k x 8 + 256B) 8MHz 1.8V - 3.6V 64-QFN T/R	Active
TPS71533DCKR	IC VOLT REG Fixed 1 50mA SOT-353 T/R	Active
ABS09-32.768KHZ-T	CRYSTAL 32.768kHz 2-SMD T/R	Active
ABMM-8.000MHZ-B2-T	CRYSTAL 8MHz 4-SMD T/R	Active
ABM8-26.000MHZ-10-1-U-T	CRYSTAL 26MHz 4-SMD T/R	Active
LMV751M5	Op Amp Standard 5MHz SOT-753 T/R	Active (NRND)
CC1100RTKR	RF Transceiver (Board Mount) TxRx Only General ISM < 1GHz 20-QFN T/R	Active (NRND)
MC44BS374T1AEF	NTSC/PAL Modulator Audio/Video, VCR's, Set-Top Boxes 16-SOIC Tube	Obsolete
BP2C+	RF Power Combiner and Divider 960MHz 8-SOIC T/R	Obsolete
SI9988DQ-T1	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 650mA 8-SOP T/R	Obsolete
LP38693SD-ADJ	IC VOLT REG Adjustable 1 REG 9V 500mA 6-SON T/R	Obsolete (Unconfirmed)
LM4881MM/NOPB	Audio Amplifier Class AB Headphones, 2-Channel (Stereo) 300mW x 2 @ 8Ohm 8-SOP	Active

The components that were found to be obsolete will require alternatives, which will have to be researched and approved for a redesign. This process is outside the scope of this document, but a preliminary alternative search will be conducted in order for there to be a thorough understanding of the kind of work that is required for a redesign.

3.2 Component Alternatives

An initial search was performed where several potential component alternatives were compiled into lists. These lists were downscaled and assembled into Appendix 1.

These component searches are still very dependent on having a person with the availability to conduct manual research on individual components. Software such as Z2Data has been developed to assist with these kinds of endeavors by having databases with updated information on a wide host of electronic components that is accessible through filtering, but these programs are often above the price point of many smaller companies and still require a great deal of human input and common sense to find suitable alternatives for replacement [18].

LMV751M5 has a direct substitute in LMV751M5/NOPB: the two components share the same datasheet and specifications. A similar situation can be viewed in appendix 1, in the search performed for LP38693SD-ADJ: the manufacturer's code changed to LP38693SD-ADJ/NOPB without having any other changes done to the component itself. This information must, however, be updated accordingly for logistic purposes.

LP38693SD-ADJ, SI9988DQ-T1, BP2C+, CC1100RTKR and MC44BS374T1AEF have proven to have no direct substitutes during a manual search. This means that internal discussions would have to be had in order for the company to decide on whether to allocate resources to adapting the existing circuit to new components or rebuilding the circuit entirely.

These potential substitute lists must be examined by a lead designer so that incompatible alternatives are not introduced, but they can be incorporated and consulted for future EOL cases once approved, thus streamlining the process of component replacement for posterity. Some components, such as MC44BS374T1AEF, may prove to be crucial for the product's functionality, and yet not have similar enough counterparts; this may, as previously mentioned, later lead to another circuit redesign with a new microcontroller in mind.

4 Technical Analysis

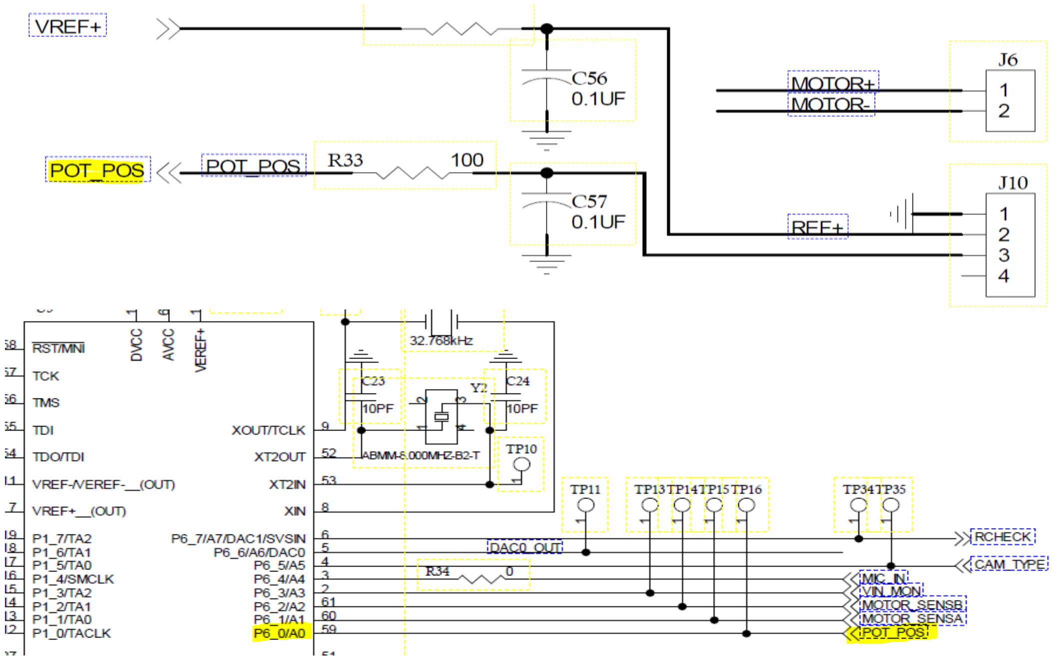
4.1 Schematic Analysis

The SearchCam 3000 has a high level of functionality, which necessitates rather extensive circuitry. This document shall therefore only disclose the parts of the circuit that interact with or relate to the sections that handle the rotation of this product's camera.

The SearchCam 3000 has the MSP430F1611 microcontroller as its main hub when it comes to user input. MSP430F1611 interfaces with the SearchCam 3000's VDU (shown below in Figure 16) to provide video and audio feedback and to allow for user input related to that feedback (picture caption, video caption, audio output).

Figure 16. Depiction of the SearchCam 3000's VDU [19].

In its current design, input related to the camera's rotation is taken from the potentiometer, whose output value is given from the voltage division between its resistance and a reference voltage (VREF+). MSP430F1611 reads the output of the potentiometer and communicates with SI9988 to drive the motor to rotate accordingly, as can be seen below in Figures 17 and 18:

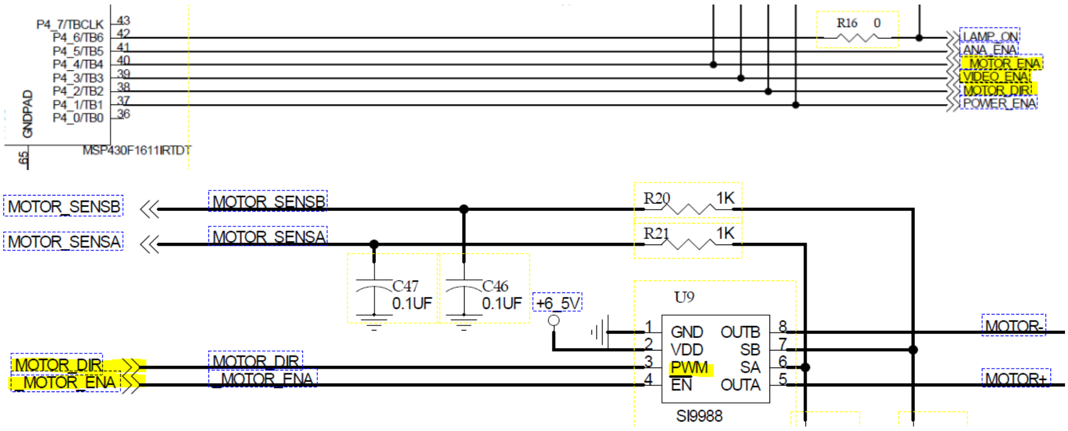


Figures 17 and 18. Schematics show that the voltage is read from the potentiometer and fed directly to MSP430F1611. Two additional inputs (MOTOR_SENSB and MOTOR_SENSA) from SI9988 allow MSP430F1611 to read motor direction.

The planned redesign means to remove the potentiometer so that MSP430F1611 reads the input set by the user through a different component.

According to available company schematics, pin groups P4 and P6 seem to be the outputs from SI9988 and the potentiometer, respectively, that go into MSP430F1611. According to SI9988's datasheet [14], pulling $\overline{EN}$ on SI9988 to a logic high forces the motor to break [14]. The PWM signal sent from MSP430F1611 to SI9988 will cause it to vary the average voltage applied to the motor, controlling its speed.

It may be possible to implement this redesign based on what can be gleaned from the above schematics. It may be possible to program MSP430F1611 to handle a new kind of input, as it already appears to be handling audio and imaging parameters and does so with the current potentiometer input. Figures 19 and 20, shown below, illustrate that pin 39 from MSP430F1611 enables the video output and show the section of the schematic where the PWM is being handled.



Figures 19 and 20. The MOTOR_DIR output from MSP430F1611 sends a PWM to the motor driver and _MOTOR_ENA signals that the motor is running. VIDEO_ENA suggests that MSP430F1611 is responsible for enabling the VDU as well.

The schematic portion for the video and audio modulator, MC44BS374T1AEF, can be seen below in Figure 21. The figure shows that the output for those two parameters is given to the VDU through two DN connectors. It does not appear to handle motor control information in any way.

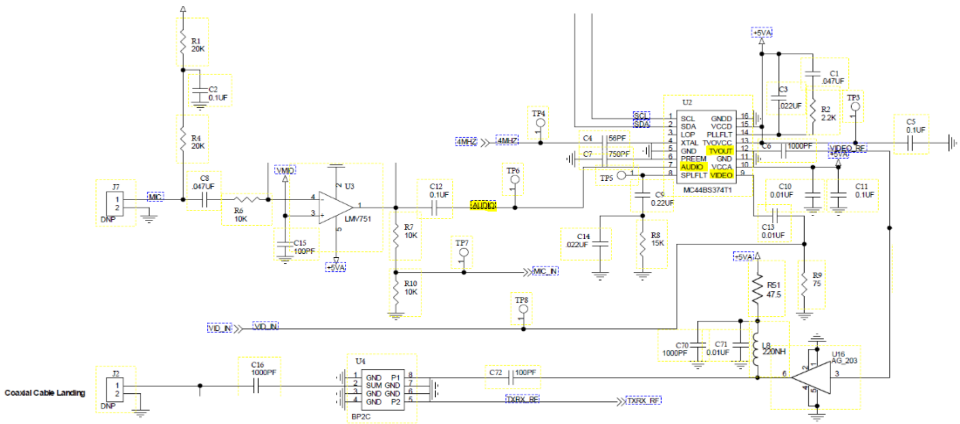


Figure 21. Schematic segment of MC44BS374T1AEF. Sound and audio are modulated and sent to DNP connectors that interface with the VDU.

A closer look at the source code that oversees the logic within MSP430F1611 is required in order to derive further conclusions on how to obtain the necessary data that would convert user input into a voltage that can drive the motor without the use of a potentiometer.

4.2 Source Code Analysis

The source code for the SearchCam 3000 was compiled in C. MSP430F1611 can be programmed through a flash programmer with its own dedicated software [20].

While Savox has provided uncompiled source code for analysis, this flasher device does not appear to be available, which implies that implementation will have to remain theoretical.

The source code responsible for the DC motor control is appropriately named ‘Motor_Ctrl’ and is likely to be the most relevant programming file in terms of this study’s scope. Figures 22 and 23, shown below, show portions of the code within this file. ‘Motor_Ctrl’ interacts with ‘Camera,’ with ‘Init_Data’ (which is responsible for reading and writing initialization data to/from FLASH), with ‘ADC12_Drvr’ (likely responsible for the control code which has the ADC converter read the input voltage that comes from the potentiometer), and with other routines unrelated to the rotation of the camera.

The VDU source code is a great deal more extensive and will not be disclosed unless strictly necessary. It possesses ‘usart,’ ‘timer’ and ‘keypad’ routines that are likely to be relevant for an attempt at creating user-set directions, but will not be elaborated on, given that it has been previously established that the VDU does not manage any function concerning the motor’s position and subsequent camera rotation.

‘Usart’ contains subroutines that are responsible for enabling and clearing UART, USART and SPI on the MSP430 [23; 24; 25]. Serial communication will make use of the ‘timer,’ which provides the clock signal information that will have a logic signal oscillating between a HIGH and LOW state to help synchronize all interfacing components, ‘Motor_Ctrl’ controlled components included.

‘Motor_Ctrl’ appears to be responsible for all of the logic that drives the motor’s position and speed. It initializes the motor and sets a timer and setpoints for it. These setpoints make use of a couple of functions that read the camera’s position and calculate whether it requires resetting or not. Upon initialization, the camera’s position is always reset. It turns off the motor entirely if the ‘motor is stopped’ and ‘motor is at position zero’ flags are found to be true (and resets the motor position again if the ’motor is at position zero’ flag is not true).

Port P4 is defined at the start of this file’s code as being the port that reads the current. There is a dedicated function for checking whether too much current is being fed to the motor; this function will back off the motor’s setpoint values for both camera angle and position in order to avoid going over the preset current threshold. It also ensures that the flags responsible for signaling whether the motor is at zero and stopped are updated accordingly.

```
#define     MOTOR_ENA_LINE          BIT4
#define     MOTOR_DIR_LINE          BIT2

#define     MOTOR_SEL_PORT          P4SEL
#define     MOTOR_OUT_PORT          P4OUT
#define     MOTOR_DIR_PORT          P4DIR

#define     MAX_CURRENT_THRESHOLD    250

#define     MAX_CAMERA_ANGLE        120

static struct
{
    UINT16   Min;
    UINT16   Mid;
    UINT16   Max;
}Motor_Setpoints = { 0,2048,4095 };
//}Motor_Setpoints = { 0,2048,/*4095*/3800 };//testing values before calibrated method

static volatile UINT16  Motor_Position              = 0;
static volatile UINT16  T                           = 0;
static volatile BOOL    Stop_Flag                   = FALSE;
static volatile BOOL    Zero_Motor_Flag             = FALSE;

static UINT16           Motor_Position_Setpoint     = 2048;
static float            Ramp_Period                 = 20.0;
static float            G                           = 1.5;  // Larger value produces faster motor movement.
static int              Stop_Position;
#define MAX_PER_VAL     50      // Larger value produces faster motor movement.
#define CLUTCH_ANGLE    5
```

Figure 22. Opening code for ‘Motor_Ctrl’.

There is a ‘Motor_Setpoints’ array declared at the beginning of ‘Motor_Ctrl’ that fixes the position of the motor according to its values for testing and a ‘Motor_Position_Setpoint’ integer that matches the middle value of that three-variable array. This last integer is the setpoint position which the motor will attempt to reach when it is on and is not meant to be fixed outside of testing. It is instead likely to be determined by what P4 provides.

```
void Motor_Ctrl_Initialize( void )
{
    // initialize the IO pins and stop the motor
    MOTOR_SEL_PORT &= ~( MOTOR_DIR_LINE );
    MOTOR_SEL_PORT |= ( MOTOR_ENA_LINE );
    MOTOR_DIR_PORT |= ( MOTOR_ENA_LINE | MOTOR_DIR_LINE );

    // set up Timer_B to generate a pulse
    TBCTL   |= ( TBSSEL1 );     // use smclk, divider 1
    TBCCR0  = TIMER_B_PERIOD;
    TBCCTL4 |= ( OUTMOD_2 );     // set output mode 2 (set/reset)
 //   TBCCTL4 |= ( OUTMOD_2 | CLLD_1 );     // Test!! set output mode 2 (toggle/reset), Compare latch load source : 1 - TBR counts to 0 */
    TBCCR4  = 0;
    TBCTL   |= MC0;             // start "up" mode

    Read_Init_Data( &Motor_Setpoints.Max, sizeof(Motor_Setpoints.Max), &Motor_Setpoints.Max );
    Read_Init_Data( &Motor_Setpoints.Min, sizeof(Motor_Setpoints.Min), &Motor_Setpoints.Min );
    Read_Init_Data( &Motor_Setpoints.Mid, sizeof(Motor_Setpoints.Mid), &Motor_Setpoints.Mid );
    Motor_Position_Setpoint = Motor_Setpoints.Mid;
    Stop_Position = 0;
}
```

Figure 23. 'Motor_Ctrl''s initialization function.

There is a ‘T’ variable which seems to work together with the ‘Ramp_Period’ value to determine whether to stop the motor or not depending on the angle of the camera.

A ‘G’ variable is also declared; this value is used in the ‘Control_Loop’ C file and seems to play a part in the ‘P’ parameter of its ‘PID’ functionality. This section can be viewed in Figure 24, shown below:

```
case Proportional:
    Current_Error   = Control_Loop_Setup.pGet_Error();
    Output          = Current_Error * Control_Loop_Setup.G + Control_Loop_Setup.K;
    Control_Loop_Setup.pSet_Output( Output );
    break;
```

Figure 24. Proportional Case of 'Control_Loop', responsible for the PID control of the DC motor.

‘G’ is set to a fixed value in ‘Motor_Ctrl’ and will increase or decrease the motor’s speed if that value is set higher or lower, respectively.

‘Motor_Ctrl_Callback’ is the callback function responsible for updating the PWM and direction outputs based on position feedback, which is believed to be supplied by the P4 port. ‘Motor_Ctrl_Callback’ contains the variables ‘pADC_Values’ and ‘Count’ given by the ADC ISR [21]. It controls the aforementioned ‘T’ and ‘Ramp_Period’ values into stopping the motor and/or returning the camera to its original angle when a certain threshold is met by setting their respective flags to TRUE or FALSE.

The values ‘Motor_Ctrl_Callback’ reads and adjusts from P4 should be the values received from the voltage set by the ISR, which is, in the SearchCam 3000’s case, the potentiometer. If this is in fact the case, and no other coding segments are found to interfere or alter these values, then replacing the potentiometer’s values with values fed from elsewhere should be a matter of plugging in another voltage output that is within the threshold constraints of ‘Motor_Ctrl’ to P4. The manner in which this voltage would then be adjustable would depend on the replacement component and would technically require very few (if any) changes to the SearchCam 3000’s source code.

Managing the camera rotation input through the VDU would, however, require a greater circuit overhaul that involves a couple of additional microcontrollers on top of a source code rewrite, since the VDU is currently not handling any input that concerns the motor position.

5 Conclusion

The goal of this thesis was to describe the research and considerations that took place during the process of defining the feasibility of a small redesign to an existing circuit that involved excluding a previously implemented component. Like the redesign itself, the very process of documenting these tasks was not linear, and material written on the circuit’s operation required revising whenever new information on it came to light.

Initially, this research relied heavily on the suppositions derived from reading assorted online documentation that broached circuits and component behaviour similar to what the SearchCam 3000 possessed. A clear idea and explanation of why and how this redesign could be implemented was possible only through a deeper delve into the details of the circuit logic pertaining to this particular product through a closer inspection of hardware and software files.

It was only through the study of all of the components that were (tangentially or directly) related to the potentiometer to be removed and through the comparison between the schematics, their source code and similar, simpler circuit behaviours found in other resources that reaching the conclusion that this redesign would be feasible, yet not likely to be convenient, was possible.

It is now realistic to affirm that the SearchCam 3000 can indeed operate without its potentiometer, as it seems to be supplying information that can be provided by other means with little changes done to the rest of the circuit. Implementing a substitute component that oversees just the adjustable voltage division and input to the MSP430 might be an unnecessary redesign, however. There would likely be a desire to consolidate all input through one display or a desire to otherwise make the analog input as seamless as possible, which would necessitate further engineering.

It is possible to implement a small, cost-efficient pair of microcontrollers that can handle user input, display and voltage output to the MSP430 in place of the bigger potentiometer without having to change the rest of the design. Yet there are already open-source microcontrollers in the market that can, for instance, singlehandedly perform the tasks of driving DC motors through wireless input. There is, for example, a microcontroller module based on the ATmega328P known as Romeo BLE which uses wireless communication to drive a DC motor and could be programmed to function with an Arduino [26].

It was concluded that a complete circuit overhaul might be the better approach in the SearchCam 3000’s case, as a simple combination of an Arduino, a Romeo BLE and a compatible wireless audio or video module would be able to handle most, if not all, of the camera-related functions, taking up only a fraction of the space and conceivably removing the need for the current VDU.

The process of authoring this thesis has additionally given insight on the necessarily systematic nature of product management and on some of its challenges. The sourcing and maintenance of existing, separate components requires periodic surveillance of their status on the market, as well as a detailed understanding of how these components operate within a product, if that product is to be manufactured reliably. Proper version control of BOMs and schematics also proved to be crucial, and to cause delays when information has to be constantly and repeatedly tracked down. Missing documentation can lead to the impossibility of enacting a redesign or of manufacturing a product if it is not located.

In summary, the proposition of a redesign of an older, scarcely documented product itself requires investigating prior to considering allocating resources to implementation. There are many moving parts in a redesign, and while much of the innovation work is already taken care of in the initial design, a rehaul poses new, additional challenges to be overcome.

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6 Appendix 1: Alternative Component List

Alternatives found from preliminary searches for components with similar electrical/feature characteristics to the components reaching EOL. Basic information on these electrical characteristic and sourcing was added and compiled into their respective lists:

Child Stock Code	Mfr. Code	Manufacturer	Description	Lifecycle	Height/Thickness	Length/Width	Data Rate	Supply Voltage	Receiving Current	Transmitting Current	Current Consumption	Frequency	Interface	Mounting Style	Package	Min/Max Operating Temperature	Datasheet Link	Single Unit Price	Availability
EI0581	CC1100RTKR	TI	RF Transceiver (Board Mount) TxRx Only General ISM < 1GHz 20-QFN T/R	NRND	0.9mm	4.1/4.1mm	1.2kbps to 500kbps	1.8V to 3.6V	13.9mA to 15.9mA	12.3mA to 31.1mA	14.4 mA in RX, 1.2 kBaud, 868 MHz	348MHz, 400MHz to 464MHz, 800MHz to 928MHz	SPI	SMD/SMT	20-VQFNP (4x4)	-40°C to 85°C	https://www.ti.com/lit/ds/symlink/cc1100.pdf?ts=168922004093		
	CC1101RGPR	TI	IC RF TXRX ISM<1GHZ 20VFQFN	Active	1mm	4.15/4.15mm	0.6kbps to 600 kbps	1.8V to 3.6V	14.3mA to 17.1mA	12.3mA to 34.2mA	14.7 mA in RX, 1.2 kBaud, 868 MHz	300MHz to 348MHz, 387MHz to 464MHz, 779MHz to 928MHz	SPI	SMD/SMT	20-VQFNP (4x4)	-40°C to 85°C	https://www.ti.com/lit/ds/symlink/cc1101.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-	4.32	176 in-stock, 6 weeks lead time
	CC1101RGPT	TI	IC RF TXRX ISM<1GHZ 20VFQFN	Active	1mm	4.15/4.15mm	0.6kbps to 600 kbps	1.8V to 3.6V	14.3mA to 17.1mA	12.3mA to 34.2mA	14.7 mA in RX, 1.2 kBaud, 868 MHz	300MHz to 348MHz, 387MHz to 464MHz, 779MHz to 928MHz	SPI	SMD/SMT	20-VQFNP (4x4)	-40°C to 85°C	https://www.ti.com/lit/ds/symlink/cc1101.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-	5.2	2214 in-stock, 6 weeks lead time
	CC1101RGP	TI	IC RF TXRX ISM<1GHZ 20VFQFN	Active	1mm	4.15/4.15mm	0.6kbps to 600 kbps	1.8V to 3.6V	14.3mA to 17.1mA	12.3mA to 34.2mA	14.7 mA in RX, 1.2 kBaud, 868 MHz	300MHz to 348MHz, 387MHz to 464MHz, 779MHz to 928MHz	SPI	SMD/SMT	20-VQFNP (4x4)	-40°C to 85°C	https://www.ti.com/lit/ds/symlink/cc1101.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-	5.2	184 in-stock, 6 weeks lead time

Child Stock Code	Mfr. Code	Manufacturer	Description	Lifecycle	Height/Thickness	Length/Width	Insertion Loss	Frequency	Mounting Style	Package	Min/Max Operating Temperature	Datasheet Link	Single Unit Price	Availability
EI0586	BP2C+	Mini-Circuits	RF PWR DVDR 810MHZ-960MHZ	Obsolete	1.96mm	6.35/5.33mm	0.4dB	810MHz to 960MHz	SMD/SMT	8-SOIC	-40°C to 85°C	https://www.minicircuits.com/pdfs/B		
	QCN-12A+	Mini-Circuits	RF PWR DVDR 800MHZ-1.25GHZ 6SMD	Active	0.89+-0.06mm	3.20+-0.06/1.6+-0.06mm	0.4dB	800MHz to 1.25GHz	SMD/SMT	6-SMD	-55°C to 100°C	https://www.minicircuits.com/pdfs/QCN-12A+.pdf	17.07€	3125 in-stock, 11 weeks lead time

Child Stock Code	Mfr. Code	Manufacturer	Description	Lifecycle	Height/Thickness	Length/Width	Supply Voltage Range	Output Voltage Range	Output Current	Quiescent Current	Mounting Style	PSRR	Package	Min/Max Operating Temperature	Datasheet Link	Single Unit Price	Availability
	LP38693SD-ADJ	TI	IC VOLT REG Adjustable 1 REG 9V 500mA 6-SON T/R	Obsolete	1.8mm	6.5/3.56mm, 3/3mm	2.7V to 10V	1.25V to 9V	500mA	100µA	SMD/SMT	55dB	SOT-223/WSON	-40°C to 125°C	https://www.ti.com/lit/ds/symlink/lp38691-adj.pdf?HQS=dis-dk-null-		
	LP38693SD-ADJ/NOPB	TI	IC VOLT REG Adjustable 1 REG 9V 500mA 6-SON T/R	Active	1.8mm	6.5/3.56mm, 3/3mm	2.7V to 10V	1.25V to 9V	500mA	100µA	SMD/SMT	55dB	SOT-223/WSON	-40°C to 125°C	https://www.ti.com/lit/ds/symlink/lp38691-adj.pdf?HQS=dis-dk-null-	1.8€	no-stock, 20 weeks lead time

Child Stock Code	Mfr. Code	Manufacturer	Description	Lifecycle	Height/Thickness	Length/Width	Supply Voltage Range	Output Voltage	Quiescent Current	Output Current	I/O Gain	Output Configuration	Power Dissipation	Stepper Motor Type	AC/DC Motor Type	Interface	Mounting Style	Package	Min/Max Operating Temperature	Datasheet Link	Single Unit Price	Availability
EI0608	SI9988DQ-T1	Vishay	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 650mA 8-SOP T/R	Obsolete			3.8V to 13.2V			650mA		Half Bridge (2)		Bipolar	Brushed DC, Voice Coil	PWM	SMD/SMT	8-TSSOP	-40°C to 150°C	https://www.vishay.com/docs/71376/71376.pdf		
	BD6962FVM-TR	ROHM	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 800mA 8-SOP T/R	Active	0.9mm	2.9+-0.1mm/4+-0.2mm	3.3V to 14V	0.6V		800mA	51dB (max)	Half Bridge (2)	0.85W		Brushed DC, Brushless DC	PWM	SMD/SMT	MSOP8	-40°C to 105°C	https://fscdn.rohm.com/en/products/databook/datasheet/ic/motor/fan/bd6962fvm-e.pdf	Digikey: 1.59	6000 in-stock, 20 weeks lead time
	ZXBM5210-SP-13	Diodes	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 8-SOIC T/R	Active	1.75mm	6.10/4.95mm	3V to 18V	0.25V at 500mA	0.85mA	1500mA (max)		Half Bridge (2)			Brushed DC	PWM	SMD/SMT	8-SO-EP	-40°C to 105°C	https://www.diodes.com/assets/Datasheets/ZXBM5210.pdf	Digikey: 1.04	167520 in-stock, 16 weeks lead time
	ZXBM5210-S-13	Diodes	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 8-SOIC T/R	Active	1.45mm	4.9/3.85mm	3V to 18V	0.25V at 500mA	0.85mA	1500mA (max)		Half Bridge (2)			Brushed DC	PWM	SMD/SMT	8-SO	-40°C to 105°C	https://www.diodes.com/assets/Datasheets/ZXBM5210.pdf	Digikey: 1.04	28518 in-stock, 16 weeks lead time
	MAX22201ATC+T	Analog Devices	Motor Driver ICs Driver - Fully Integrated, Control and Power Stage 3.5A 12-SON	Active		3/3mm	3V to 36V		6.5µA(sleep mode) 4mA (not in sleep mode)	3.5A (max)		Half Bridge (2)	1951.2mW at 70°C	Bipolar	Brushed DC	PWM	SMD/SMT	12-TDFN-EP (3x3)	-40°C to 125°C	https://www.analog.com/media/en/technical-documentation/data-sheets/MAX22201-MAX22207.pdf	Digikey: 2.02	2259 in-stock, 25 weeks lead time