Design Document

Lens Controller for Biomedical Cameras

Team 26

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Introduction

Problem

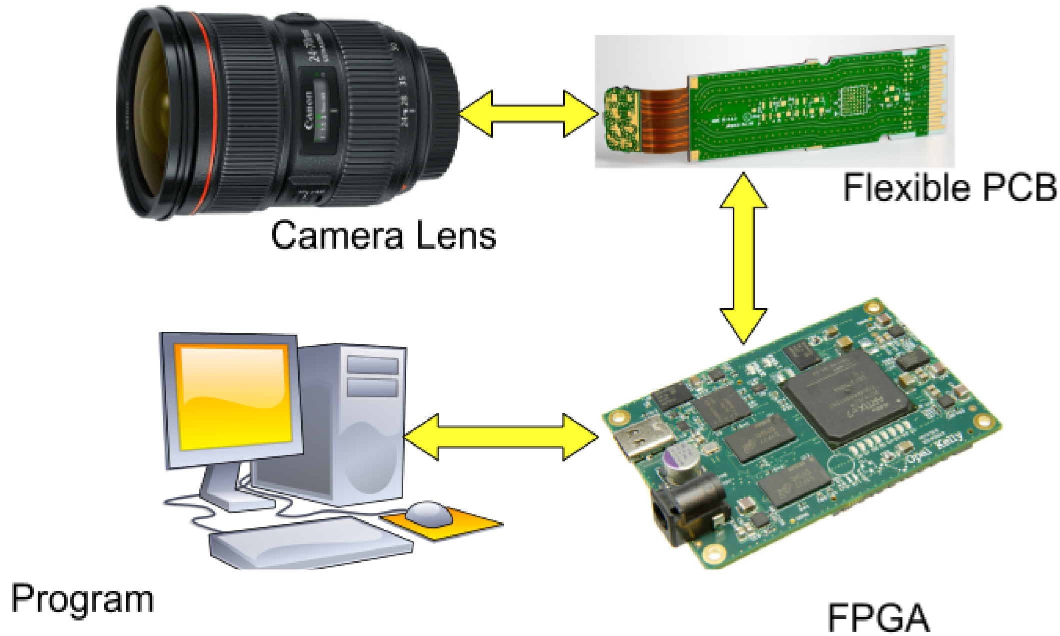
In many operations, the margin for error is very slim. This is especially true for cancer treatment, where operation on tumors is considered one of, if not the only solution to cancer sickness. Operating on tumors requires a high degree of accuracy and so, the use of cameras to aid surgeons in the operating room would significantly reduce the risks associated with any mistakes involved in the removal of tumors. According to a study, incomplete tumor removal occurs in 25% of breast cancer patients, 35% of colon cancer patients and 40% of head and neck cancer patients [1]. From this, it can be seen that the problem is significant and requires a solution to this problem.

Solution

The solution to this problem is to develop a system where the lens of the camera can be adjusted based on a user input (A surgeon or surgery assistant) remotely, which would then help the surgeons in identifying any cancerous tumors and fully removing the tumors.

We are planning to use the FPGA to move the lens of the camera so that users can remotely control the lens from their computer. The flexible PCB board will provide the connection between the FPGA and the lens due to the incompatible port assignments of the two components, which the flexible PCB will be responsible for correctly handling . We will be implementing a finite state machine and using the FPGA to control the overall operation of the camera. Users will be interacting with the movement of the camera using python code from their computer, by inputting their preferences for camera operation.

Visual Aid



High-level requirements list

Aperture Functionality

Requirement : The lens must be able to change the aperture by the correct amount based on the command input by the user.

Focus Functionality

Requirement : The lens must be able to change the focus length by the correct amount on command input by the user.

The correct functionality of the camera lens will also be indicative of the correct mapping of the ports. This is important as it would indicate that the lens is receiving the correct signals from the FPGA and also outputting the correct signals back to the FPGA for user feedback. The user would then be able to adjust the camera's magnification based on the output and would then issue new focus parameters which will then be sent back the same way. The operation of the camera lens will be controlled by the FPGA using Verilog code and the data signals will then be transported by a modified SPI protocol through the flexible printed circuit board. The user will be able to input their instructions into the computer using a Python program which will then be converted by the FPGA board's API interface for use by the FPGA.

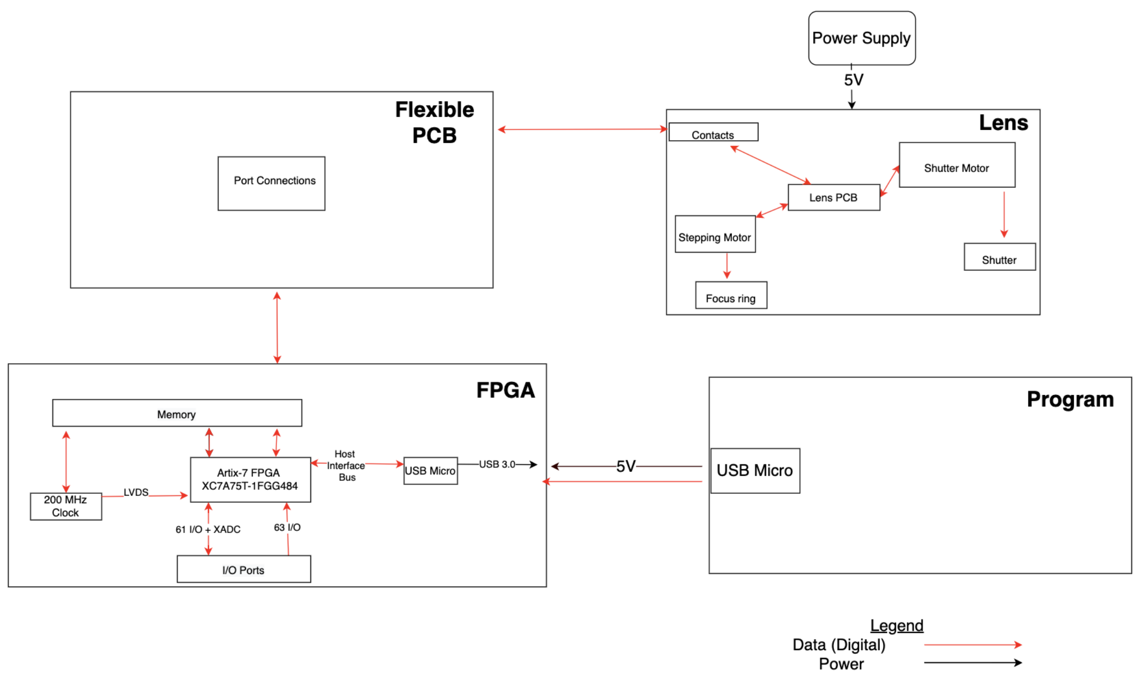
Long Term Operation Reliability

Requirement : The system can run for at least 6 hours.

We need to ensure that the long operation time does not affect the functionality of the camera. The FPGA program should not be entering into the forbidden states even with a long operation time. We decided to implement our system for at least 6 hours as that seems to be roughly the average time for cancer operations [2]. This is an important requirement as the camera lens needs to work in an operation-like setting and operations can last multiple hours.

Design

Block Diagram



Subsystem Overview

FPGA

The FPGA board component for our project is the XEM7310-A75 and XEM7310-A200 by Opal Kelly. It is an easy to use, high performance, and reliable FPGA that will be used as a hardware accelerator in our design. The primary FPGA is an XC7A75T-1FGG484 FPGA which requires a voltage supply of around 0.95 to 1.05 V to operate. It also has flash and SDRAM components that form the memory store for the board. The board has an important feature in the form of the complete Application Programmer's Interface (API) that is specific for the Python language which is necessary for our project. It has 126 user I/O ports and has a SuperSpeed USB 3.0 interface port. Overall, the FPGA board will be communicating in between the computer subsystem and the Flexible PCB subsystem, based on the HDL code written by us.

The FPGA will interact with the PC through the USB 3.0 port and control the lens using I/O pins through the flexible PCB board. The FPGA board will be receiving a power supply of 5V from the computer through the USB 3.0 port.

We will be using two FPGA boards. The reason why we are using two FPGA boards is that the XEM7310-A75 board will be used for the testing portion while the XEM7310-A200 board will be used for the actual design. We dedicated one FPGA board for the testing portion so that we can work on verilog code for the FPGA while preparing the PCB board. In this way we can parallelize the workload to speed up the project.

<u>Requirement</u>	<u>Verification</u>
1. The FPGA must be able to control the operation of the lens when the users type in commands in their PC 2. The FPGA must be able to communicate in between the camera lens using the 7-pin ports and the PC through the USB port.	1. Plug the FPGA board to the computer through the USB port. 2. Load the program to the FPGA board. 3. Send the command to the FPGA from the PC using python code. 4. Users will have to check whether the lens functions correspondingly.
3. The FPGA must be able to maintain its operating temperature with the prolonged sustained work without overheating. (~2 hours)	1. Create a python code that runs the FPGA for a specified time. 2. Connect the FPGA to the PC and load the program. 3. Attach temperature sensor to the FPGA board 4. Run the program 5. Monitor the temperature of the FPGA
4. The FPGA must not enter a forbidden state after prolonged operation.	1. Create a testbench in verilog that contains loops (while or for) that runs the FPGA for a prolonged period of time. a. The testbench should be able to keep track of how many times it enters into each state and show how many times it did not enter the required states. 2. Run the testbench and check output generated by the testbench.

5. The FPGA must be able to halt at any state when the halt signal is fed in.	1. Create a testbench that inputs a halt signal while the FPGA is undergoing a set of states. a. Counter should be implemented to check how many times the input signal is fed in and how many times the FPGA itself enters into the halt state. 2. Run the testbench and check output generated by the testbench.

Flexible PCB

The flexible PCB board will be providing interconnection between the FPGA board and the Canon camera lens. On the PCB board, there will be circuit components to help enable the transfer of data from the FPGA board to the lens. We are using the flexible PCB for two reasons: The contacts on the lens are very thin and also the port assignments between the FPGA and lens are incompatible. A flexible PCB would be better suited as it can handle multiple port assignments and through the specific sub-model of the flexible PCB known as a flat flexible cable, be able to perform the function of wires in transporting data signals. This will allow better connection with the fine contacts on the lens and allow the FPGA and lens to communicate through the reworked port assignments. Furthermore, this data will be transferred using an 8 bit modified SPI protocol which will be responsible for handling the seven data signals involved.

Some advantages of the flexible PCB include the fact that it is very flexible and thus can be used in a wider range of applications. In addition, there is very little wire connection which increases its reliability by preventing accidental shorting as with traditional PCBs which have that possibility. They take up less physical space and are much easier to use and transport, however their storage procedure is much more complicated and must be done properly. Going off those same lines, these flexible PCBs are very easily damaged and hard to repair, as they take a longer time to manufacture in the first place due to its complexity and eventual simplicity. The cost of resources is higher, but as such there can be greater circuit density on the boards.

In our implementation, we can use the concept of the flexible PCB in multiple ways. In one way, the flexible PCB would be implemented in its full capability where we would bend the circuit board in order to reduce space and to accommodate the lens' inconvenient port setup. This would involve calculating and designing the mechanical parameters of a flexible circuit board such as the bend angle, appropriate thickness, bend radius and the frequency of flexing [2]. This would be our ideal option as it would allow the camera lens to be used without any further changes.

An alternative strategy would be to use a flexible PCB but utilizing it as a cable wire. This means that it would be implemented as a wire without any bending while still delivering the signals from both the FPGA and camera. This process would be much simpler as we would not have to calculate the mechanical parameters and would also be more likely to work given the relative simplicity compared to the first design as explained above.

Requirements	**Verifications**
1. Series resistance	1. Prepare the multimeter. 2. Use the probes of the multimeter to test two points on the PCB board to check the series resistance.
2. Capacitance between two lines	1. Prepare the multimeter. 2. Use the probes of the multimeter to test two points on the PCB board to check the capacitance between the two lines.

Lens

This camera lens is a widely used and reputable product that is one of the main cameras that photographers use. To start, this camera has a lens that has a high-performance zoom that is compatible with EF-S lenses. In addition, one of its main features is its image stabilization mechanism. This Image Stabilizer provides the equivalent effect of that of a shutter speed but four stops faster [3]. Certain conditions such as still objects as well as following moving objects. There is also an aspheric lens that allows for excellent imaging performance as claimed by their manual [3]. Among this performance metric is the ability to shoot very clean closeups at all focal lengths, and lastly there is a round aperture hole that results in the background blur being particularly smooth. The camera lens will have the focus mode switch set to manual so that the user can change the focus according to their own specifications.

The lens will interact with the power supply subsystem as it will be powered through a 5V supply and will also interact with the flexible PCB to receive instructions on how to adjust the appropriate camera features.

Requirements	Verifications
1. The lens can adjust focus to maximum and minimum values 2. The lens can adjust aperture to maximum to minimum values	1. Run the verilog code on FPGA 2. Run Python code 3. Observe if the camera focuses or changes aperture according to the user input
3. The lens shutter opens within one second of running code The lens is able to execute the commands with less than 0.5s of latency.	1. Run the verilog code on FPGA 2. Run Python code 3. Observe if the camera properly opens its shutter. Successful observation will be enough to pass this test
4. All the instructions are executed reliably over 6 hours	1. Run the verilog code on FPGA 2. Run Python code 3. Check the correct operation after running the program for 6 hours.

Program

The program component will be implemented through the use of a personal computer or laptop. It should provide HDL code, written in Verilog, to the FPGA board. The USB port of the PC will be responsible for sending the HDL program to the FPGA board as well as providing its power. The USB port will be outputting 5V DC voltage and will be connected to the USB port on the FPGA board using a USB cable. Furthermore, it will also provide the Python code utilized by the user to adjust camera features.

The program component will mainly be communicating with the FPGA subsystem to effectively operate the camera lens.

Requirements	Verifications
The machine has to run for 6 hours	1. Run the program on the PC for 6 hours. 2. Check power usage, memory usage, and other metrics that a computer runs on.
The Python code has to be implemented correctly	1. Run Python code 2. Check visually to see if lens responds to commands
The machine has to power and run programs on the FPGA.	1. Write a testbench to check the verilog code that we wrote is correct. 2. Compile the program and run the program with testbench. 3. Check the waveforms to see if we are going through the correct states and send correct signals to the lens 4. Measure power drawn by the FPGA as the program is running to ensure it is within limits.

Tolerance Analysis

FPGA

As our project involves a lot of programming, we need to ensure the reliability of the operation even after running the program for an extended period of time. An operation would be multiple hours in length, if not more and so we must make sure there are no unexpected crashes or errors. By doing this, we minimize the chance of ineffective tumor removal as discussed in the Introduction. In particular, the Finite State Machine, which is mainly responsible for the implementation of the various instructions put into the camera, has to continuously run for as long as the operations take, and we need to ensure that nothing breaks down in the middle of its functions.

This will be done by simulating the Finite State Machine to make sure that it steps through all the states effectively. Furthermore, the ability to simulate will also allow us to see the entire operating cycle of the Finite State Machine which will allow us to more effectively diagnose and solve any potential errors or faulty states.

Flexible PCB

Another challenge that needs to be considered is the design specifications of the flexible PCB. Due to its unique nature, the flexible PCB needs to be designed very carefully in order to maximize its usefulness to the system. There are several factors that need to be considered when designing a flexible PCB. These include bend angle, bend radius and whether the board can bend statically or dynamically. The thickness of the board will be a variable that can help in determining these factors.

The first decision to make is whether the PCB will be static or dynamic. The difference here is that a static flexible PCB will not be able to withstand another flex after it has been designed while a dynamic flexible PCB can withstand the board being flexed again after design [11]. In our system, the flexible PCB will not be required to be flexed again and so, the choice is made to design a static flexible PCB. Furthermore, design and cost constraints also support these decisions as seen below, when calculating bend radius and discussing bend angles.

According to PCBWay, their PCBs have a range of thickness between 0.08 mm to 0.4 mm [14]. Based on the IPC Standard 2223-B, the bending radius and the thickness are proportional to each other [11]. This is seen in the table below. Therefore, we can calculate a minimum and maximum value for the bend radius based on the minimum and maximum thickness values.

	Ratio	Thickness
Single Layer	6	1
Double Layer	12	1

[11]

Based on the fact we are implementing a static flexible PCB and a single layered PCB, the bend radius needs to be at least six times larger than the thickness of the board [11]. According to the thickness values above, this means that the minimum and maximum bend radii are as follows:

Minimum Bend Radius:

$$Bending\ Radius\ =\ Thickness\ \times\ Ratio\ \times\ No\ of\ Layers$$
$$Bending\ Radius\ =\ 0.08\ \times\ 6\ \times\ 1$$
$$Bending\ Radius\ =\ 0.48\ mm$$

Maximum Bend Radius:

$$Bending\ Radius\ =\ Thickness\ \times\ Ratio\ \times\ No\ of\ Layers$$
$$Bending\ Radius\ =\ 4\ \times\ 6\ \times\ 1$$
$$Bending\ Radius\ =\ 24\ mm$$

Based on the calculations, the bending radius is between 0.48 to 24 mm. From a design perspective, we would want the PCB to be as thin as possible and so that would also affect the bend radius as well. Therefore, we would like the bend radius to be as close to 0.48 mm as possible.

Another factor that is considered is the bend angle. For our system, this angle will be determined by the alignment of the lens and the FPGA. The FPGA will be housed in a specific unit with the port connecting it to the lens being in a very specific location. Furthermore, the ports on the lens are at a very awkward angle and so, the most likely solution would be to have the PCB flex at different angles throughout the length of the PCB. For example, in the regions near the FPGA and the lens, the PCB would flex at certain angles to align it with the ports on the FPGA and lens whereas in the regions in between the FPGA and the lens, the angle would be relatively small.

Cost and Schedule

Cost

Component	Manufacturer	Quantity	Price
XEM7310-A75	Opal Kelly	1	$569.95
XEM7310-A200	Opal Kelly	1	$734.95
BRK7010	Opal Kelly	1	$49.95
Camera lens	Canon	1	$199.99
			Total Parts Cost = $1,554.83

The average hourly salary of a graduate electrical engineer is $38. [12]

We will be working approximately 13 hours per week for 10 weeks. Therefore:

$$\$38/hour \times 130\ hours = \$4,940\ per\ person$$

$$Total\ Labor\ Cost = \$4,940 * 3 = \$14,820$$

Our project does not require any labor from the machine shop.

Hence:

$$Total\ Project\ Cost = Total\ Labor\ Cost + Total\ Parts\ Cost = \$16,374.84.$$

Schedule

Week	Task	Person
Oct 3-7	1. Start reviewing project equipment and documentation. 2. Disassemble camera to analyze lens ports for PCB design. 3. Finish PCB ideation and design in preparation for ordering. 4. Start working on FSM and run through reviews with BioSensors lab staff	Kevin: 1, 2 Jihun: 1, 3, 4 Sid: 1, 3, 4
Oct 10-14	1. Oct 11th deadline to submit orders. 2. Continue working on FSM. 3. Complete Team Evaluations.	Kevin: 1, 3 Jihun: 2, 3 Sid: 2, 3

Oct 17-21	1. Implement PCB (if it arrives) into the system to test functionality and synergy. 2. Simultaneously work on the flat PCB as a backup. 3. Start Python code to control user features and experiment with separate components.	Kevin: 1 Jihun: 3 Sid: 2
Oct 24-28	1. Integrate all systems together for an initial prototype of the final camera system.	Kevin: 1 Jihun: 1 Sid: 1
Oct 31-Nov 4	1. Nov 1st second deadline to submit orders if needed. 2. Finalize initial design details and refinement iterations.	Kevin: 1, 2 Jihun:1, 2 Sid: 1, 2
Nov 7-11	1. End of initial design process.	Kevin: 1 Jihun: 1 Sid: 1
Nov 14-18	1. Mock demo. 2. Improve on the design based on the feedback from the mock demo.	Kevin: 1, 2 Jihun: 1, 2 Sid: 1, 2

Nov 28-Dec 2	1. Final demo.	Kevin: 1 Jihun: 1 Sid: 1
Dec 5-9	1. Final presentations + papers	Kevin: 1 Jihun: 1 Sid: 1

Ethics and Safety

Ethics:

Regarding ethics, there are a few potential concerns that we will address throughout the project. IEEE Section I-1: “To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;” [4] and ACM 1.6: “Respect privacy.” [5] states that we must always protect the privacy of others. Because we are working with a camera, there is always the issue of privacy when recording and collecting data. There will need to be consent and confidentiality measures taken to ensure proper usage of the camera.

IEEE Section II: “To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others.” [4] as well as ACM 1.2: “Avoid harm.” [5] states that we must not injure or bring harm to others, and this will work concurrently with our efforts to minimize potential physical harm to others as much as possible. No matter which part of the entire contraption, none of it should have the possibility of harming anyone in the vicinity.

Last but not least, we must always uphold the code of conduct among every engineering organization, among our colleagues and in regards to everything that we do as stated by IEEE Section III: “To strive to ensure this code is upheld by colleagues and co-workers.” Aside from the specific points of each code mentioned above, we must always look to follow and practice the code in its entirety at all times.

Our Canon lens is classified as a Class B device by the FCC, and as such follows the following requirements: “...emission limits are specified for frequency ranges of 0.45-1.6 MHz and 1.6-30 MHz. While FCC radiated emission limits are specified for frequency ranges of 30-88 MHz, 88-216 MHz, and 216-1000 MHz at a fixed measuring distance of 3 meters. These limits apply to both systems with SMPS installed and SMPS in stand-alone applications.”

Having specified the requirements for the device for use in the general public, they follow the OSHA regulations as specified by the ICRP (International Commission on Radiological Protection): “Under ICRP guidelines, occupational exposure should be limited to a maximum average of 20 mSv per year over a five-year period, with no exposure greater than 50 mSv in a single year.” As these numbers are very foreign to us, as well as having an incredible amount of legal minutia in which we are not experts in, we believe that because the device has already passed regulatory requirements for general use, it would be able to be used in a medical setting in a similar fashion.

To further back up our assumption, an an answer from OSHA themselves regarding devices in the operation room, they stated an answer as follows: “if a hospital-selected safety device or work practice would adversely affect patient safety, the hospital must ensure that an alternative safe device or practice is implemented for the handling of sharps in the OR. For example, in a situation where all practicable engineering devices have been implemented and it is not feasible to perform the surgical procedure safely using a neutral zone, the hospital must ensure that surgeons and other staff in the operating room do not perform "hand-to-hand" passing of devices without first verbally notifying each other. In this way, operating room nurses, technicians, and surgeons will not be caught off-guard and will thus avoid "blind" retrieval of contaminated sharps.”

To finalize the discussion of whether or not devices that can give off interference that might disturb processes within the operating room, the observations have been as follows so far: “Institute of Electrical and Electronics Engineers (IEEE) Committee on Man and Radiation (COMAR), (September 2000). Reports that sufficiently high levels of RF energy can interfere with other electronic equipment. This problem is more likely to occur with pulsed energy, which characterizes digital cellular telephones. Studies have shown that handheld cellular phones can affect the operation of heart pacemakers or defibrillators if the phone is placed directly over the device, and there have been reports of interference between cell phones and hearing aids.” As we can see, the camera itself will not be a significant source of a pulsing electromagnetic radiation, and thus will indeed be allowed into the surgical suite.

Regarding the power component of our system in the face of regulations, the US Department of Labor has set forth electrical standards covering everything that our project could possibly have, and the page in question is linked below.

Safety:

As with any mechanical contraption, there is always a risk of the machine malfunctioning and worst case scenario, exploding. The PCB will need to be structured properly, as any mismatching connection can cause a short circuit. The camera breaking down during its intended operation will also pose a risk to the patient, and we most definitely want to avoid this. However, for the scope of our project, this will not be a main concern.

Regarding the camera lens, there are a few precautions that the manufacturer themselves have warned about in the manual. To quote the Canon manual “Whether it is attached to the camera or not, do not leave the lens under the sun without the lens cap attached . This is to prevent the lens from concentrating the sun’s rays, which could cause a fire. If the lens is taken from a cold environment into a warm one, condensation may develop on the lens surface and internal parts. To prevent condensation in this case, first put the lens into an airtight plastic bag before taking it from a cold to warm environment. Then take out the lens after it has warmed gradually. Do the same when taking the lens from a warm environment into a cold one. Do not leave the lens in excessive heat such as in a car in direct sunlight. High temperatures can cause the lens to malfunction.” [3]

Another potential risk that they have stated in their disclaimers is the fact that there is no guarantee that the interference will not occur in any particular installation. It is of course tested and compliant with part 15 of the FCC regulations for a class B digital device, designed to provide reasonable protection against harmful interference in a residential installation. As such, the camera can generate, use, and radiate radio frequency energy, and if not adhered to the proper usage regulations, may cause harmful interference to radio communications or television reception. Should this happen, there are instructions for the user to attempt and correct the complication.

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