Wood Fuel Engine Control Unit
Senior Project Design

Feasibility Report

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1 Introduction

This report describes the feasibility of the designing and building and Engine Control Unit (ECU) for operating on non-uniform fuels. Oil prices all over the world the are expected to grow significantly in near future rendering biofuels such as wood gas more attractive than standard fuels for reproducibility. A properly operating wood gas engine also causes less air pollution compared to gasoline. However, the use of wood gas limits the output of the combustion engine, which means that the speed and acceleration of the converted vehicle are reduced. An electrical controller unit for the ignition timing of a wood-fuel-powered engine is proposed, which will attempt to maximize the fuel efficiency of the engine using measurement and control techniques.

A brief description of the project immediately follows this introduction and talks about how the engine control unit will be designed to meet the specifications. A more detailed discussion of design stages and relevant constraints will be given in the design section. Plans for testing the engine control unit, equipment and part requirements, and estimated costs will be discussed in the execution section. Finally, the teamwork section will give information about the background of the project partners and how the collaboration between the two will be held.

2 Description

When operating an engine on non standard fuels such as biodigester methane or wood gas, it is often necessary to modify the timing to compensate for a slow flame speeds caused by the presence of dilutants such as carbon dioxide or nitrogen. This capstone will investigate the possibility of creating a retrofittable controller which will control the ignition timing of an engine in order to maximize its power output on varying fuels. The device will use input data from both the engine timing voltage signal, exhaust gas temperature, and exhaust oxygen concentration to generate feedback-control for the ignition timing.

2.1 Standards

Engineering Standards will be considered throughout this project as they relate to both circuit design and testing. The Society of Automotive Engineers (SAE) issues agreed-upon standards relating to ignition system measurements ($J973\_201306$), exhaust gas temperature measurements (AS428), and engine technologies in general. The primary benefit of conforming to these standards is helping to ensure transferability of the end-product to other developers throughout the industry. Without standards, many independently effective products may exist for related purposes, yet be completely incompatible, posing hazards to safety as well as usability. However, following standards may involve extra expense and will certainly involve additional time-commitment from the project team, for whom time is a limited resource.

2.2 Ethics

Item 1 of the IEEE Code of Ethics concerns "accept(ing) responsibility in making decisions consistent with the safety, health, and welfare of the public." The overall concept of this project satisfies this guideline due to an existing impetus for engineers to create novel renewable energy solutions. With some variation, industry experts and government-sponsored studies agree that at predicted rates of consumption, fossil fuels including coal, gas, and oil will be totally depleted by the end of the 21st century. Thus, it is critical to the public welfare that technology make the inevitable transition to total renewable energy usage a smooth one. The Wood-Fuel Engine Control Unit is designed to increase the efficiency of energy extraction from wood, a definitively renewable source, via existing combustion engine technology. Success in this goal will contribute to the public good and is therefore an ethical goal.

Another ethical guideline specific relevant to this project is described in Item 7 of the IEEE Code of Ethics: "(we agree) to credit properly the contributions of others." The engine control unit to be implemented will be largely dependent on the extensive existing body of work in the fields of ignition timing and engine efficiency. Additionally, this project is an educational one, and guidance from professors, professionals, and external documentation will play an important role in producing a final functioning unit. Respecting intellectual property rights of all these sources, by providing clear citations and distinguishing all original work, will hold the highest priority.

Lastly, specifically ensuring the health and safety of nearby persons during the building and testing of the project is a critical ethical duty. Temperatures and AC voltages present in an engine are at potentially lethal levels, and improper operation of engine timing could lead to a sizable gas explosion. Rigorous design, simulation, checking and rechecking of all connections prior to any kind of testing, and standard safety equipment such as goggles and rubber gloves during testing will all be employed to minimize risk.

2.3 Other Constraints

The most strongly-defined constraint of this project is the time-limit. During the Fall 2017 semester (ECE 402) there are 15 weeks available for work, during which each of two project partners plans to commit 12.5 hours per week. As such, the pair will attempt to divide necessary tasks in the most efficient manner possible, according to their primary skills. As both partners are pursuing electrical engineering degrees, they will strive to minimize microcontroller programming work and divide such work equally. Both partners will be closely involved with the design of all hardware electronics, but will divide some development and testing between themselves, with Berkay focusing more on voltage-protective circuitry and Graham focusing more on signal conditioning circuitry.

Economic constraints immediately affect the funds available for use in this project, both for the purchase of parts and testing equipment. Although prices of electronics in general are not likely to vary widely within the coming year, revisions to the project design will affect cost. Fortunately, the combination of funds from the ECE department, from project sponsor Stephen Abbadessa, and from the two project partners provides a comfortable buffer for such variations.

Environmental considerations will play a key role in this project, which includes repeatedly running a pollutant-producing engine. Testing of the ECU will occur both with gasoline- and wood-fueled engines, and will be performed in the outdoors. Protective measures will be put into place to ensure that as little as possible unnecessary pollutants are released into the environment; these pollutants include fuel as well as electrical components.

3 Design

While detailed development of this project idea is ongoing, the fundamental design and sub-elements have been planned and are laid out in block diagram format in Figure 1.

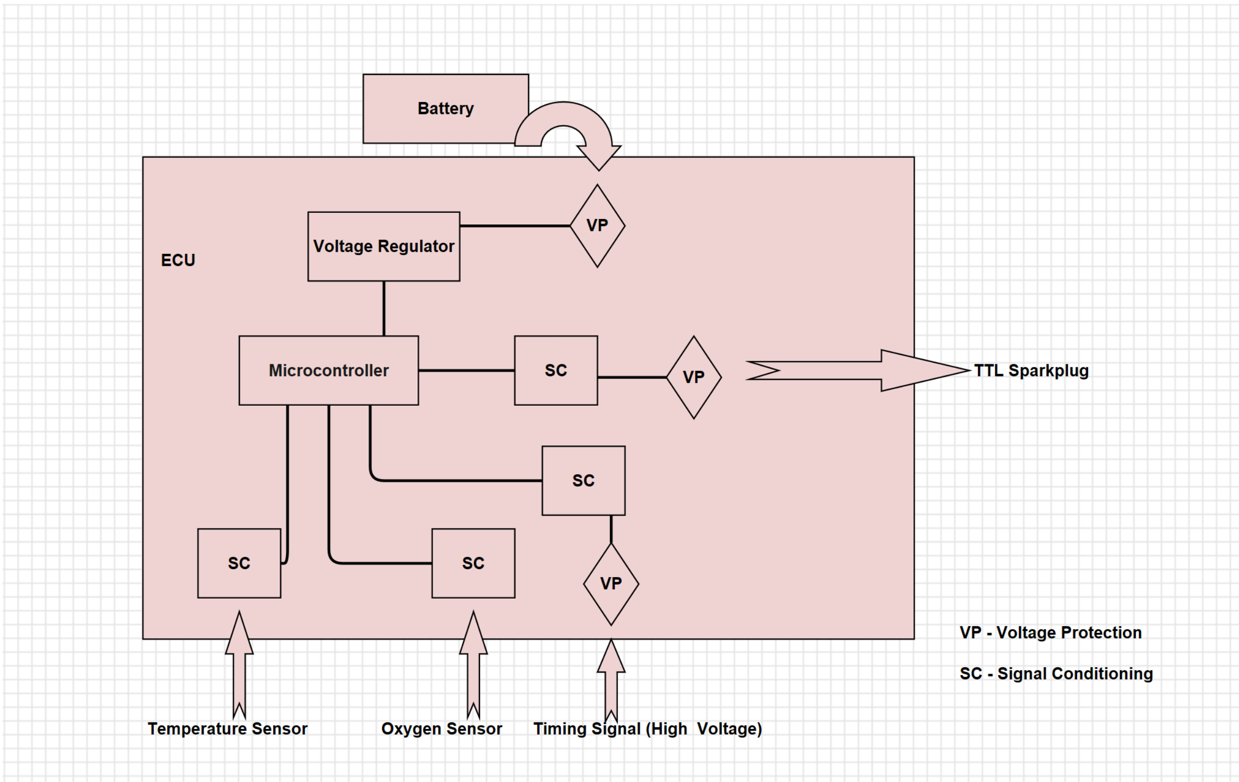

Figure 1: Block Diagram for Engine Control Unit Design

The project design outlined above may be divided into three distinct stages: data collection from the operating engine, data analysis via microcontroller, and signal output to ignition system. While these three stages together form a fairly unique application of electrical systems, none of the component stages are so complex as to be infeasible. For each, there is documentation available online for similarly-purposed devices; this is especially true for the final stage, as a wide diversity of open-sourced ignition techniques have been perfected by amateur and professional car-enthusiasts alike. Additionally, the individual guidance of Stephen Abbadessa, from whom the project idea originated, will be very helpful due to his experience with wood-fueled engines and their ideal operating conditions. Overall, the design has been analyzed from a wide perspective and found to have strong potential to achieve all deliverables required of this project.

Several input signals are seen in Figure 1: collected analog signals from temperature and oxygen sensors, and the high-voltage engine timing signal. The temperature and oxygen sensors are intended to provide live data on how the engine is performing; any additional heat content in the engine exhaust is wasted energy that was not converted to mechanical work, and so signals inefficiency in the engine. Oxygen content in the exhaust can help in identifying the current fuel-to-air ratio in the combusting fuel. A decreased fuel-to-air ratio is present in wood-sourced fuel, including slow-burning nitrogen in particular, and this fuel-to-air ratio exhibits random variance due to physical shifting of fuel inside the preceding gasifier stage. The speed of the flame front after ignition is decreased by this less rich fuel, leading to the pressure peak occurring later in each cycle than is optimal for the engine, and so a decrease in extractable mechanical work. Advancing the timing of the engine has the potential to correct for this difference in fuel quality, but measurements of the fuel-to-air ratio are needed with as short a time-resolution as possible, as these sensors may indirectly provide.

The timing signal consists of short voltage spikes spaced according to the desired sparking frequency, and is generated by the existing engine system. In a simple engine-controller, these spikes would directly initiate the ignition process, perhaps with some constant phase delay tuned to engine geometry. Figure 2 demonstrates a standard four-stroke engine cycle, including the timing of the ignition spark.

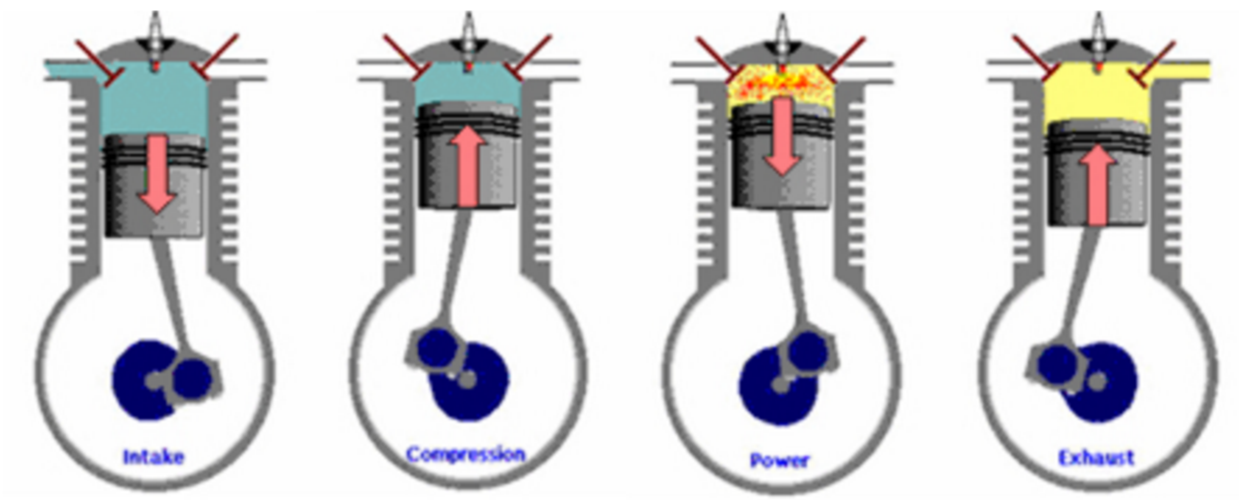

Figure 2: Four Stroke Engine Cycle [Source: Youtube, CARS Channel]

Ideally, the timing signal from the engine would serve as a baseline, from which the microcontroller would calculate the time-delay corresponding to a desired timing phase shift. Given the present angular speed ω of the engine and the desired phase shift ϕ, the necessary time-delay is defined by the relationship

$$\Delta t = \omega \cdot \phi. \tag{1}$$

Therefore, for an advance in timing as represented by a negative value of ϕ, the time delay Δt must also be negative. Yet until the timing spike from the engine has been received, it is not possible to know just when the spike would occur ahead of time, in order to precisely advance the phase. Significant error would be gathered if time were counted from the previous timing signal spike, hindering the desired precision of the phase control.

Certain design constraints are applicable to each of the stages of the design, and have impacted the planning of this project. The high voltages inherent in gas-powered engines have strongly influenced design, as the data-collection stage must step-down these high voltages to a level at which they may be safely analyzed by a microcontroller, while the output stage must produce a voltage signal of this same high magnitude to properly fire the spark plug at each ignition firing. Protection of the microcontroller and input sensor devices from signal surges is critical for long-term functionality of this product. Many valid voltage protection circuits exist, but one which may function particularly well is an active crowbar circuit. A single-use crowbar circuit is shown in Figure 3.

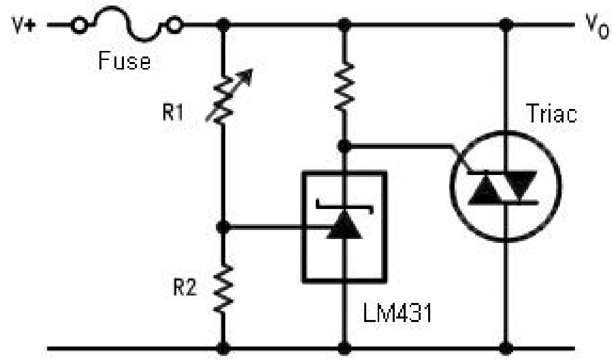

Figure 3: Crowbar Circuit Diagram (credit Wikimedia Commons)

The LM431 zener regulator device shown in the above diagram has a switching voltage which may be set by the resistor ladder R1-R2. Its diode voltage difference would then allow the passage of AC current signals through the Triac only when the signal voltage is below a certain limit. A backup fuse is also included for any dangerously high voltage which might harm the voltage protection circuit itself. However, due to the properties of the Triac, this circuit remains in the 'closed' state, once activated, until power is reset. An active crowbar circuit improves upon this by replacing the Triac with a gate turn-off (GTO) thyristor, effectively a Triac which may be reset periodically by a control voltage, enabling continued operation between voltage spikes as is requisite for this project.

Another important constraint in this project is the resolution of the output signal, which must have phase controlled to the accuracy of $\pm 1°$. Without such precision, ignition timing could not be controlled with adequate sensitivity to benefit the efficiency of the engine, or the engine might not even function at all. Finally, computing for data analysis faces a specific time constraint of 13 ms, the minimum duration between ignition firings for an engine operating at maximum 4500 rpm. For effective feedback control of the ignition timing, each ignition pulse must be shifted appropriately based on the data from the prior pulse, and so all relevant analog and digital operation to computation must be completed during this timespan. In order for $\pm 1°$ phase precision to be achieved at this frequency, the microcomputer timer must be able to accurately measure timesteps as small as $37 \mu s$. For

A microcontroller will lie at the core of the engine control unit. All the sensors used in this project will be connected to the microcontroller which will enable us to convert analog information to digital information and analyze the crucial data. The needed microcontroller for this project should have a high CPU Clock Frequency in order to perform the timing measurements with high accuracy. For this reason, the Arduino Nano was chosen, with a CPU clock frequency of 16 MHz, allowing 600 clock cycles to count the minimum required timestep mentioned above. The Arduino board has 8 analog I/O pins with the maximum allowable input voltage range of 0-5V. The board has 32 kB of flash memory for code, which will provide a reasonable constraint upon the number of instructions which may be included in project software. Arduino is accompanied by many easy-access online resources and provides a convenient programming environment, another reason why it has been chosen over other microcontrollers. It is possible that the development of this project will lead to more strenuous requirements upon the microcontroller, in which case another model (likely another Arduino) will be selected for substitution.

4 Execution

Overall, the costs associated with this product will be covered by the generous support of Stephen Abbadessa, Crosby Lab Manager at the University of Maine, who proposed this project. The necessary equipment for application of this engine controller, namely the "gasifier" which produces wood-based fuel for the engine, and the engine itself, are already fully-functioning and available for use in the Crosby Lab. Additionally, a workspace has been set aside for this project in the Crosby Lab, where electrical testing may be performed and equipment may be stored, including the engine. Any testing that involves operation of the engine may be performed outside the front entrance of the Crosby Lab, for safety reasons. Much of the other test and measurement equipment necessary to confirm operation of the design, has already been made available in this laboratory. Oscilloscopes, function generators, digital voltmeters, and some low-power supplies are available in the Crosby Lab, while more specialized equipment such as network analyzers or parameter analyzers, should they be found necessary to this work, would be available in Barrows after relevant training has been completed.

Additional parts will be required for all analog circuits implemented; while basic parts such as resistors, capacitors, and low-voltage transistors will be available from the ECE department, some others will require purchase from an online vendor. In particular, power transistors will be required for both stepping-down the measured voltage signals from the engine to a level which is safe for digital analysis, and for generating the output signal to the ignition transformer. A temperature sensor which operates well in the ranges typical of a gas engine will be purchased, as well as a solderable breadboard for organizing the analog circuits developed. These costs are summarized in Table 1 below:

Table 1: Summary of Predicted Part Costs

Component	**Distributor**	**Model Number**	**Price**	**Quantity**	**Total Price**
15 A 600 V Power Transistor	All Electronics Corp.	CATQ6015L5	1.40$	10	14$
Adjustable Voltage Regulator	Texas Instruments	TL783	14.46$	Pack of 3	14.46$
Solderable Breadboard	Adafruit	Perma-Proto 571	12.50$	Pack of 5	12.50$
Grove High-Temperature Sensor	eBay	RB-See-351	8.90$	3	26.7$
Oxygen Sensor	Autoparts Warehouse	USOS-4000	26.62$	1	26.62$
Shunt (Zener) Regulator	Digikey	FHR1200	0.363$	20	7.26$
GTO Thyristor	American Microsemiconductor	809 -V5 Helipot Div.	2.00$	10	20$
Arduino Nano	Arduino	Nano	22.00$	2	44.00$
12V 1.3 Ah Battery	Batteries Plus	SLAA12-1.3F	21.99$	1	21.99$
MOSFET N/P-Channel	Digikey	ALD1106/1107	2.675$	10 of each N/P	53.30$

A total cost of $240.83 for this project is estimated. In addition to the $150 funding provided for this project by the ECE department, each team member is willing to contribute $100 to project expenses, supported by earnings from each of our summer work plans. Also, in the original project concept, Stephen Abbadessa has offered to provide funding for necessary project parts on the order of $100. He may also be able to provide parts such as oxygen sensors and batteries, but it is assumed that additional quantities will be required and this is reflected in the table above. Therefore, $450 of total funding is potentially available for this project, leaving very substantial room for error in cost estimation.

5 Teamwork

This section will outline the collaboration between the project partners. There will be two people working for this project for a total of three semesters.

Berkay Payal double majors in Electrical and Computer Engineering and pursues Honors College studies at the University of Maine. Graham Van Goffrier majors in Electrical Engineering and Physics at the same institution. The two have taken many ECE classes together and have been lab partners for two consecutive years.

The partners will not be able to work on the project during the summer of 2017 as both have internships. However, they will stay in touch and continue to discuss the ideas regarding the project during this time. When the Fall term begins, each person will spend approximately 12.5 hours weekly on the project. Over the course of the 15-week semester, this will amount to 375 person-hours in total.

Analog circuit design along with microcomputer programming skills will be required for the completion of the project. Both have gained skills in designing circuits and programming microcontrollers in courses such as ECE 342, ECE 343 and ECE 271. In particular, hardware electronics experience gained by both partners in ECE 342/3 ensures the necessary capability to design, simulate, and test analog electronic circuits. Specific topics including engine operation and power electronics are unfamiliar to both team members; in these areas, experience will be gained through research in academic publications and texts, and through personal guidance from ECE professors and from Stephen Abbadessa.