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A DIGITAL TO ANALOG VOLTAGE CONVERTER EXPERIMENT FOR MICROCONTROLLER COURSE

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Abstract: Teaching modules and programming of a microcontroller through experiments is a very efficient method. Microcontroller programming usually also requires practical electronics knowledge. Variable analog voltage outputs are usually not available in common microcontrollers, but this type of signal is required for many applications. This experiment is proposed to teach digital to analog voltage conversion (DAC) using pulse width modulation (PWM) by a microcontroller. In the experimental procedure students should generate the PWM signal, develop digital to analog voltage regulator circuit, design a ripple filter, review the experimental results and answer the questions. Students are expected to observe and interpret the code writing, the digital to analog converter and ripple filter effect. This paper describes, the experimental procedure, the materials and methods used in the experiment and the main theoretical concepts, and determine the evaluation methods for the benefits of the experiment. This experiment will be applied to biomedical engineering undergraduates. Their performances will be evaluated through surrey questions and their grades.

***Keywords*:** Digital to analog conversion, pulse width modulation, microcontroller, ripple filter, laboratory experiment.

Introduction

A microcontroller is a chip that combines all the components of a microprocessor-based system with an integrated circuit. Microcontrollers are used as digital to analog to converter and analog to digital converter. Although analog to digital conversion (ADC) applications are very common, digital to analog conversion (DAC) applications are not so common but DAC is used in driving various electronic devices, sensor circuits and LED driving circuits. The aim of this experiment is to teach and let practice the students; generation of PWM signal, filter design and the regulation process of DAC.

In Başkent University, Biomedical Engineering undergraduates take electronic circuit design and programming lessons until the third grade. Microcontroller courses are thought to third-year students and it is continuation of theoretical and practical knowledge of the programming courses and circuit design courses which they took before. This experiment was prepared because theoretical knowledge would be more effective if supported by laboratory studies(Gibbins & Perkin, n.d.). This study concerns an implementation of DAC for Microcontroller Course.

This experiment aims to teach PWM signal generation, digital analog conversion and filter design in the direction of programming and electronic information that the student learns. The student is expected to generate the PWM signal by a microcontroller, convert this signal to analog using a filter, and design the required ripple filter circuit. Combining microcontroller programming with analog circuit design is expected to improve student's expertise and motivation.

- Selection and peer-review under responsibility of the Organizing Committee of the conference

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In literature, there exist several laboratory experiments that involve the design and the programming of microcontroller. Dias et all(de A Dias, da Silva, Kitani, Lagana, & Justo, 2016) describe an undergraduate course to teach microcontroller using automotive electronic systems. The course aims to improve students' hardware knowledge and software programming skills. Authors report that increasing complexity of laboratory projects make students more independent and develop their skills in project management and system integration.
Nurnberg et all (Nürnberg, Beuth, Becker, & Puente León, 2016) designed a laboratory course on microcontroller programming by processing digital signal. The aim of this course, to gain a perspective on information technology and to prepare students for more complex exercises in their later work. The students gained experiences in programming the microcontroller by solving simple tasks.

Ajao et all (Ajao, Olaniyi, Kolo, & Ajao, 2015) aim to solve the problems of developing students' understanding and skills in embedded system design by using microcontroller with applied laboratory experiments. According to this paper, this design has better conveniences over other similar works and it will lead students to build different simple systems with complex hardware circuit for research applications and industrial works.

This article explains the experiment plan and it gives the theoretical information about the components of the experiment set up. At first, it is explained how to generate PWM signal by using microcontroller. Then, technical information was given about the required filter designs and the signal values converted to digital were shown on the liquid crystal display (LCD). The success of the student on the experiment will be evaluated in three parts: preliminary work, experiment performance of the student and report. The impact of the experiment on student's motivation and understanding will be interpreted by survey questions to be asked before and after the experiment.

Materials and Methods

Pulse Width Modulation (PWM)

PWM is a technique for obtaining the analog signal desired to be produced at the output by controlling the widths of the pulses. The application of PWM technology is becoming increasingly widespread. PWM method is widely used in areas such as switching Mode power supplies, telecommunication, PIC applications and power circuits. In this experiment, the PWM signal generated by the microcontroller is used as digital data. When PWM signal is generated, two components are considered: duty cycle and frequency.

The duty cycle determines the ratio of time while the PWM signal is high to the period of the signal. Frequency is simple the frequency of the signal.

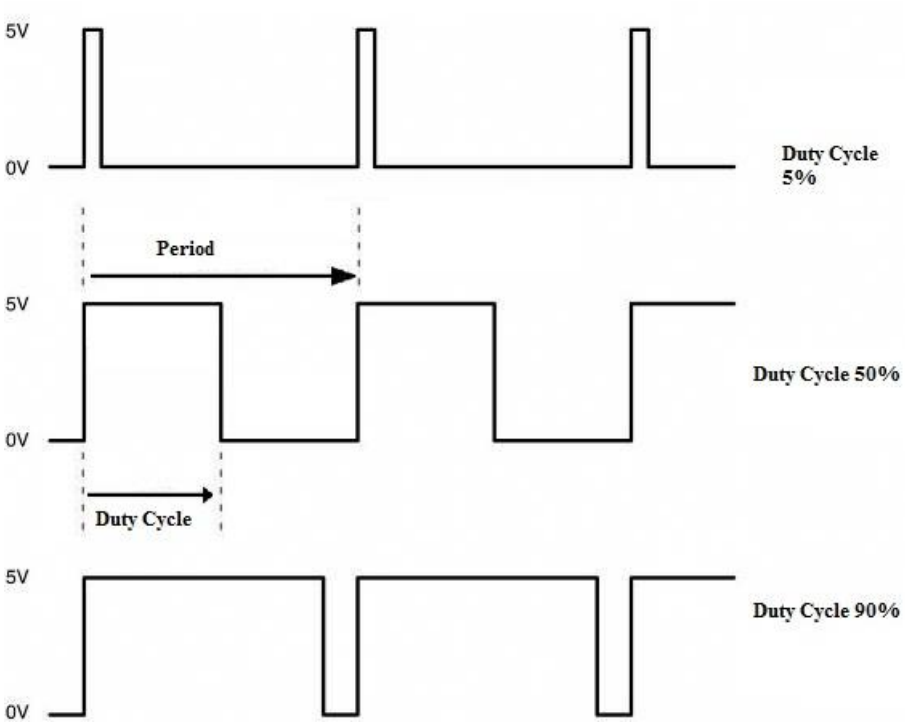

Figure 1. Duty cycle examples

In the experiment, PIC Clicker was used as microcontroller demo board for PWM generation. PIC clicker is a compact starter development kit. The duty cycle and the frequency of the PWM signal generated by the PIC clicker are adjusted through the code written by a microcontroller program According to the code, the duty cycle is increased or decreased depending on whether or not the buttons on the microcontroller are pressed.

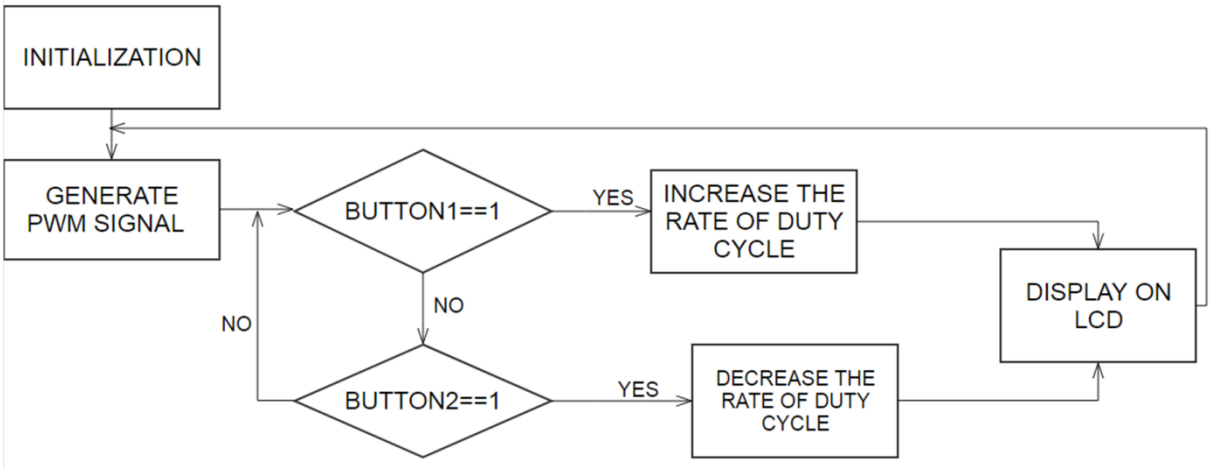

Figure 2. Microcontroller diagram

Low-pass and Ripple Filter Design

An electrical filter is a circuit that can be designed to reshape or reject all undesired frequencies of an electrical signal to transmit signals sought by the circuit designer. In this experiment design a low pass filter and a ripple filter were used .The low pass filter consisting of diode, capacitor and internal resistance of the system is used to find the DC signal corresponding to the PWM signal generated by the microcontroller. In this way, high frequency signals are blocked while low frequency signals pass. The signal obtained by suppressing the high frequency signals becomes smoother. When the PWM signal we have produced is high, the capacitor is charged. We used the diode to prevent the capacitor from discharging when the signal is low. Ripples are observed in the PWM signal passing through the low-pass filter. A ripple filter designed with using inductance and capacitor. And the ripple filter is used to eliminate these fluctuations.

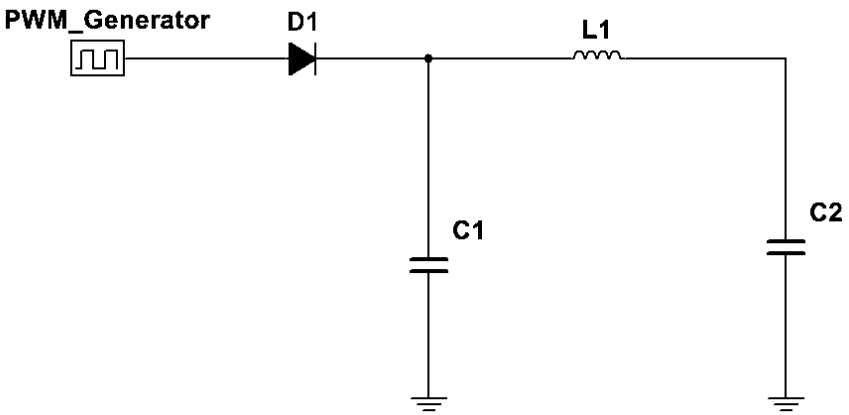

Figure 3. Filter circuits

Digital to Analog Conversion

Digital information such as 1 and 0 is referred to as digital analog conversions in circuits or integrated circuits that produce currents or voltages at different values according to the change in input values at the input and output, and this conversion is also called digital to analog conversion.

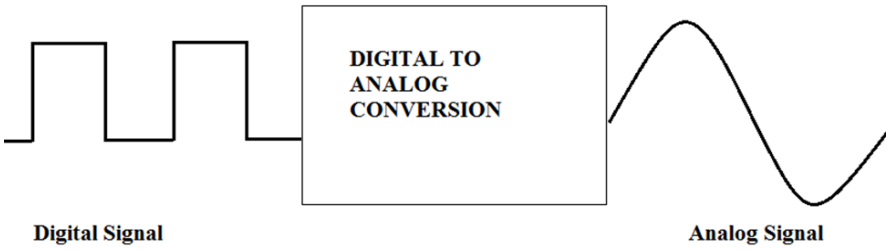

Figure 4. Digital to analog conversion

In this experiment, a microcontroller generates digital signals using pulse width modulation (PWM). The PWM signal produced to convert to analog signal has two important components; duty cycle and frequency. There is a direct proportion between the output voltage and the duty cycle. The output voltage is controlled by changing the duty cycle in the experimental setup. The PWM signals whose duty cycle was changed were observed with an oscilloscope.

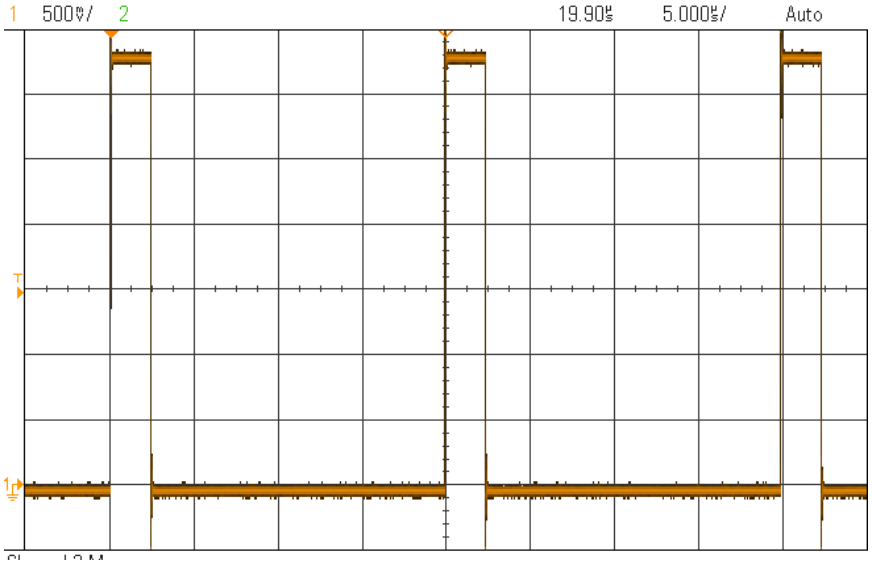

Figure 5. Image of PWM signal with 12.5% duty cycle

Experiment Design

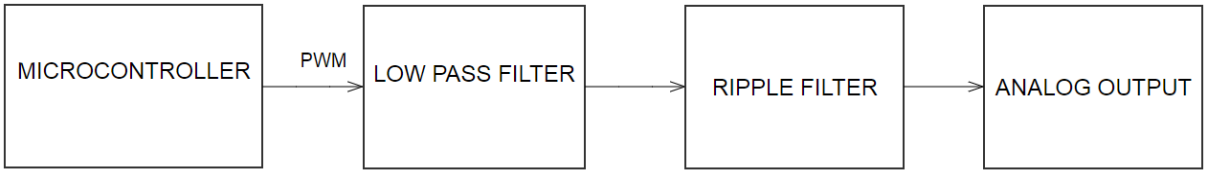

Figure 6. Experiment design block diagram

The students use the microcontroller to generate the PWM signal. First of all, students use the MicroC program to write the microcontroller code to be used in generating the appropriate PWM signal. When writing the code, the student is expected to know how to start the PWM module in the PIC Clicker demo board, set up the correct pin connections and adjust the duty cycle and make the LCD connections to display duty cycle.

After generating the PWM signal, students design the circuit that will make the necessary adjustments that will convert this signal to digital. They set up a low-pass filter circuit using a diode and a capacitor. This filter blocks the passage of high frequencies in the signal and makes the signal smoother. But this correction is not enough to create a complete digital signal. They set up a ripple filter circuit using an inductance and a capacitor to eliminate the ripples observed on the signal. In this way, a nearly flat digital signal is obtained. After that digital to analog conversion is completed. They observe the filter output through an oscilloscope and record their observations.

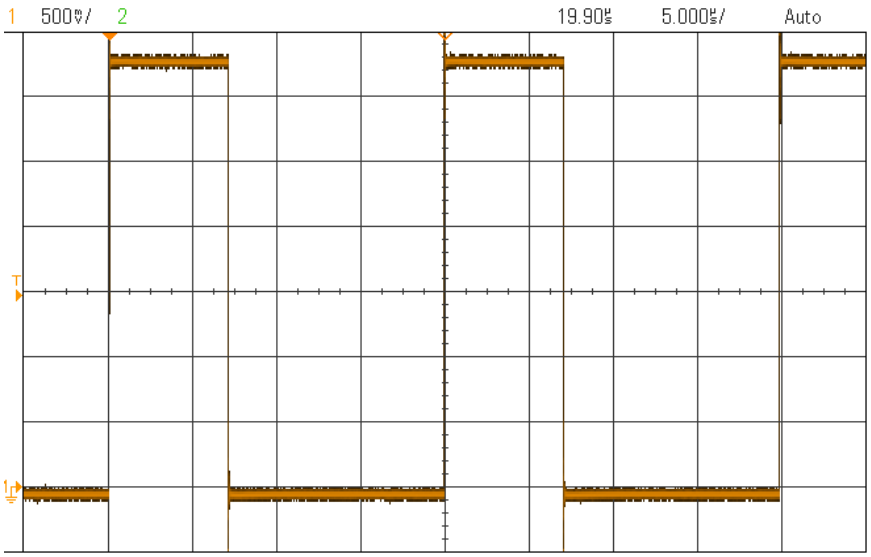

Figure 7. PWM signal

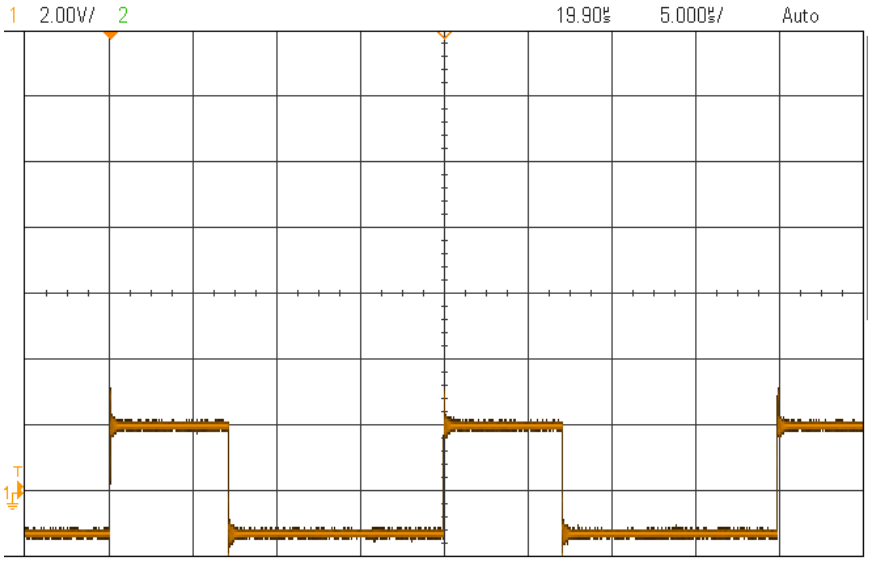

Figure 8. Effect of low-pass filter on PWM signal

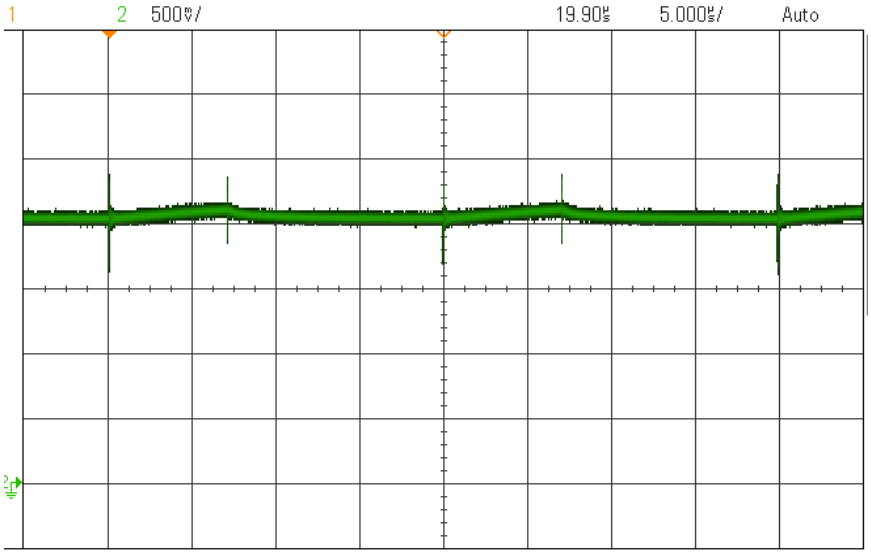

Figure 9. Effect of ripple filter on PWM signal

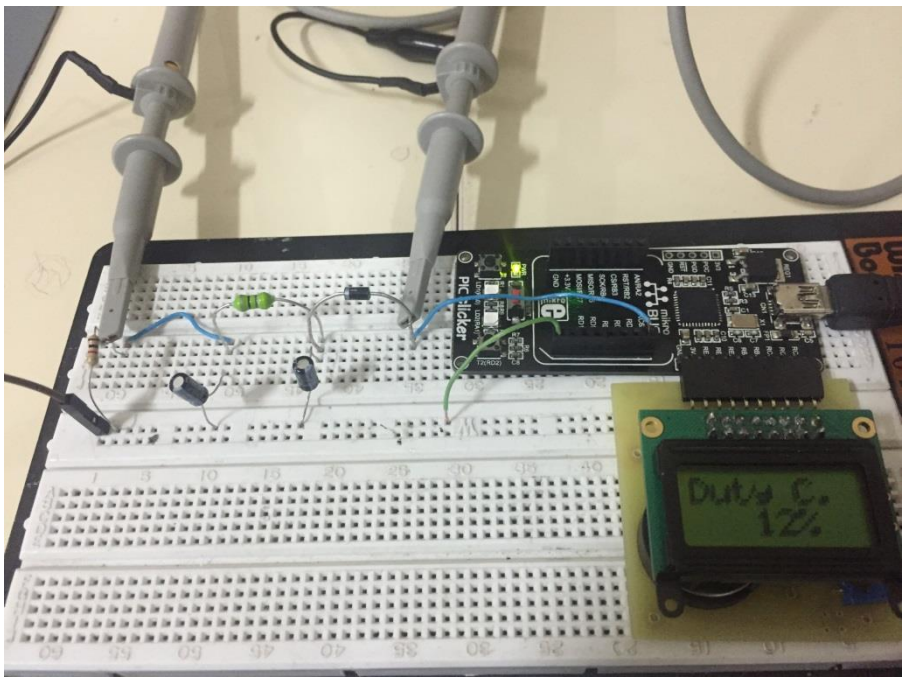

Figure 10. Experiment design

Evaluatıon Method

Questionnaires which will be applied before and after the experiment and grades will be used to evaluate the performance of the experiment. Similar studies related to the subject have been reviewed and questions in Table.1 and Table.2 are defined.(Chen et al., 2016) (Ibrahim, 2015)(Subudhi, 2016)

Table 1. Survey questions applied before the experiment

Questions	On a scale of 1 to 5 rate: (1=very poor, 2=poor, 3=satisfactory, 4=strong, 5=very strong)
Q1	Do laboratories increase your motivation about biomedical engineering?
Q2	What are the difficulty levels of laboratories?
Q3	Do you think the laboratories help you to improve your theoretical knowledge?
Q4	Are you having trouble designing in experiments?
Q5	Do you think laboratories are complementary to the course content?

Table 2. Survey questions applied after the experiment

Questions	On a scale of 1 to 5 rate: (1=very poor, 2=poor, 3=satisfactory, 4=strong, 5=very strong)
Q1	Did this laboratory increase your motivation about biomedical engineering?
Q2	What is the difficulty level of this laboratory?
Q3	Do you think this laboratory helped you to improve your theoretical knowledge?
Q4	Did you have trouble designing in experiments?
Q5	Do you think this laboratory is complementary to the course content?

The students' laboratory success will be graded according to the preliminary work, performance during the experiment and the report they delivered at the end of the experiment.(Ogrutan & Aciu, 2017) The papers prepared for the preliminary work contain the theoretical information required for the experiment and the study questions related to the subject for the student. The performance of the students during the experiment is

assessed by the course teachers and their assistants. The report that students record observations at the time of experiment and write their inferences is graded at the end of the experiment.

Conclusion

Laboratory works including electronics design could be tough for the students. For Biomedical Engineering students it is even tougher because they should both use electronics and medical concepts. Laboratory design experiments are mandatory because they should practice theoretical knowledge. Since design is hard, general trend for students is to memorize and save the day.

In this study we offer a well-planned experiment in order to motivate students to make a design and test it. Our aim is to teach to students that generation of PWM signal, filter design, regulation process of DAC, programming microcontroller. The experiment described in this article is designed for biomedical engineering students in the third year for microcontroller laboratory at Başkent University. During the design process, students are taught how to produce the PWM signal used in many electronic applications, design the necessary filters, and program microcontrollers. The experiment design has a microcontroller for generating PWM, a low pass filter and ripple filter to regulate the generated signal, and an LCD to display the determined duty cycle.

Literature was searched for this experiment which was prepared to increase the motivation of the students and their interest in lessons. And the experiment was planned considering of researches made. Experiment will be evaluated according to the methods described in the paper.

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