# Introducing HIV/AIDS Education Into the Electrical Engineering Curriculum at the University of Pretoria

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***Abstract*—This paper describes how HIV/AIDS education is being introduced into the curriculum of the Department of Electrical, Electronic, and Computer Engineering at the University of Pretoria, Pretoria, South Africa. Third- and fourth-year students were provided with an HIV/AIDS Educational CD developed at the university. Their knowledge of the subject was tested via two quizzes—one written before they were exposed to the material on the CD and one after. In addition, a mathematical HIV/AIDS model is being incorporated into a third-year control systems course. This model is used to illustrate standard control systems engineering concepts, such as linearization, system stability, feedback, and dynamic compensation. This paper is an example of how topical nonengineering material can effectively be made part of a high-level undergraduate engineering course. Students benefit not only from the topical nature of the subject, but also from an improved understanding of control engineering concepts which can be applied to many different fields.**

***Index Terms*—Acquired immune deficiency syndrome (AIDS), control systems engineering, education, human immunodeficiency virus, immune system, modeling.**

## I. Introduction

ACCORDING to the December 2001 Acquired Immune Deficiency Syndrome (AIDS) epidemic update by the Joint United Nations Program on Human Immunodeficiency Virus (HIV)/AIDS, about one in nine South Africans (4.7 million) are living with HIV/AIDS [1]. Thus, about 10% of all South Africans are infected with HIV, and it is estimated that about 1700 new infections are documented every day. Projections suggest that by the year 2008, half a million South Africans will die every year from AIDS-related causes.

Given the dire situation described, and the realization that students generally fall into a high-risk group, the University of Pretoria has launched various initiatives to promote the understanding of the disease among its student population. Such a recent initiative was the development of an HIV/AIDS educational CD [2], developed by the Department of Electrical, Electronic, and Computer Engineering, the Department of Telematic Learning and Education Innovation, and the Centre for the Study of Aids, all from the University of Pretoria. Its development was initiated by the Control Group of the Department of Electrical, Electronic, and Computer Engineering, as part of their program on the modeling and control of HIV/AIDS.

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The CD was recently presented to about 300 third- and fourth-year Engineering students. Their knowledge of the subject was tested via two quizzes—one written before they were exposed to the material on the CD, and one after. The results of these quizzes and the contents of the HIV/AIDS educational CD are described in Section II.

Mathematical HIV/AIDS models [3] that describe the time evolution of healthy CD4+ cells, infected CD4+ cells, and the virus load make this CD of special interest to engineers. The models are packaged as Java applets, which allow the user of the CD to view the time evolution of these model outputs in graphical form. Model parameters can be adjusted by choosing different treatments, and the effects of such treatments can be seen in the model outputs. A simple HIV/AIDS mathematical model is described in Section III.

The HIV/AIDS model described in Section III has been incorporated into an introductory third-year control systems course offered by the Department of Electrical, Electronic, and Computer Engineering at the University of Pretoria. The model is used to illustrate standard control systems engineering concepts, such as linearization, system stability, feedback, and dynamic compensation, as described in Section IV.

## II. HIV/AIDS Educational CD

The HIV/AIDS educational CD was created so that it can be used as a generic HIV/AIDS educational tool by the University of Pretoria. The target market for this CD consists of undergraduate students in all disciplines at the university, although because of its generic nature, it is also relevant to the population at large. It was initially used in the Department of Electrical, Electronic, and Computer Engineering at third- and fourth-year level.

### A. Contents of the HIV/AIDS Educational CD

As stated in the introduction, the development of the CD was initiated by the Control Group of the Department of Electrical, Electronic, and Computer Engineering, as part of their program on the modeling and control of HIV/AIDS. The initial idea was to package research on the modeling and control of HIV/AIDS in this way [4], [5]. However, it soon became apparent that comprehensive explanations of terms used in the model would be required for such a CD to be a stand-alone product. A booklet developed by the Center for the Study of AIDS at the University of Pretoria [6] to train AIDS counselors was, therefore, incorporated to form the basis of required background material. What follows is a brief summary of the contents of the HIV/AIDS educational CD.

TABLE I
RESULTS OF A GENERAL KNOWLEDGE HIV/AIDS TEST

| | Number | Test 1: μ (%) | Test 1: σ (%) | Test 2: μ (%) | Test 2: σ (%) |
|---|---|---|---|---|---|
| 3rd-year | 168 | 40.3 | 13.0 | - | - |
| 4th-year | 133 | 39.1 | 15.9 | 71.1 | 11.5 |

1) *Introduction*: An introduction to HIV/AIDS and the reasons for developing the CD are given here.
2) *Time line*: This section gives a brief history of HIV, including how it is spreading throughout Southern Africa.
3) *What is HIV/AIDS?* Here, the differences between HIV and AIDS are explained, and animations demonstrate HIV infection, the HIV life cycle, and drug development.
4) *Statistics*: This section shows the worldwide spread of AIDS over time and also gives specific statistics for South Africa.
5) *South Africa*: This section describes the spread of HIV in South Africa and the high-risk groups and factors contributing to the epidemic.
6) *Prevention*: Safer sex practices with information on preventive measures, vaccines, and risk factors are given here.
7) *Transmission*: This section discusses how transmission occurs and describes which bodily fluids are infectious.
8) *Diagnosis*: The blood tests (e.g., ELISA, Western Blot, and PCR), which are used to diagnose HIV, are discussed with an explanation of the window period, i.e., the period between the onset of HIV infection and the appearance of detectable antibodies to the virus.
9) *Symptoms*: The symptoms to expect after being infected with HIV are discussed, as is the asymptomatic period where no obvious symptoms are observable.
10) *Treatment*: Treatment is discussed, using the HIV life cycle to explain the purpose of the three main categories of antiretroviral drugs currently in use, i.e., nucleoside reverse transcriptase inhibitors, nonnucleoside reverse transcriptase inhibitors, and protease inhibitors. Concepts such as drug resistance are also described.
11) *Sexually Transmitted Infections (STIs)*: A discussion on STIs is included here because the presence of an STI indicates unprotected sexual behavior that puts people at risk for HIV infection. An increased chance of HIV transmission occurs when another STI is present since STIs serve as avenues for HIV to enter the bloodstream.
12) *Model*: Third- and fourth-order HIV/AIDS mathematical models are used here to describe the interactions of healthy CD 4+ cells, infected CD 4+ cells, and free viruses, using predator–prey type relationships [3]. The models are packaged as Java applets, which allow the user of the CD to view the time evolution of these model outputs in graphical form. Model parameters can be adjusted by choosing different treatments, and the effects of such treatments can be seen in the model outputs.

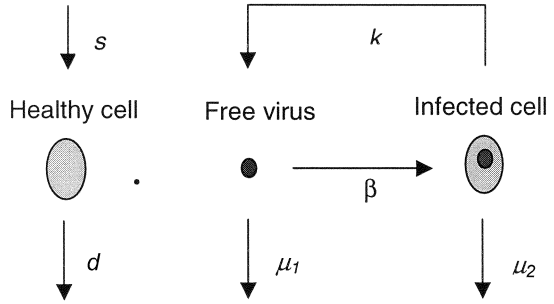


Fig. 1. Schematic illustration of the basic HIV model.

These models will be discussed in more detail elsewhere in this paper.
13) *Counseling*: This function is one of the main goals of the Center for the Study of Aids at the University of Pretoria. Because of the psychosocial impact of HIV/AIDS, counseling is considered necessary, especially before and after HIV testing. Counseling is also an important part of prevention to help people to negotiate safe sexual behavior and to provide support for the infected.
14) *Gender Issues*: Most strategies to prevent the spread of HIV/AIDS have focused on the promotion of condom use, reduction in the numbers of sexual partners and treatment of STIs. The social, economic, and power relations between men and women, among men, and among women are often not addressed. This section, therefore, analyzes gender stereotypes and looks at the defining of male and female relationships and roles.
15) *Law/Rights*: Promoting human rights in the context of HIV/AIDS is not only an imperative of justice to overcome existing forms of discrimination and intolerance, but it is also a tool to prevent the further spread of the epidemic. Although several changes have been made to existing legislation, discrimination is still a reality as people are denied jobs, accommodation, access to facilities, and basic equal rights on the grounds of their HIV status.
16) *Peer education*: This section discusses what it takes to become an "AIDS" peer educator.
17) *References*: The CD contains a comprehensive list of references, including PDF-files of journal articles published in a special issue of the *South African Journal of Science* on HIV/AIDS research in South Africa [7]. This issue reviews the recent work on the origin, prevention, and treatment of the epidemic.

TABLE II
HIV MODEL PARAMETERS

| Parameter | Description | Typical value and units |
|---|---|---|
| $t$ | Time | days |
| $d$ | Death rate of uninfected T cells | 0.02 per day |
| $k$ | Rate of virions produced per infected T cell | 100 counts cell$^{-1}$ |
| $s$ | Source term for uninfected T cells | 10 mm$^{-3}$ per day |
| $\beta$ | Infectivity rate of free virus particles | 2.4 x 10$^{-5}$mm$^{-3}$ per day |
| $\mu_1$ | Death rate of virus | 2.4 per day |
| $\mu_2$ | Death rate of infected T cells | 0.24 per day |

### *B. The CD and a General Knowledge HIV/AIDS Test*

A copy of the HIV/AIDS educational CD was presented to each third- and fourth-year student of the Department of Electrical, Electronic, and Computer Engineering in a communications module. The handing out of the CD was accompanied by a lecture on HIV/AIDS that consisted of a short handwritten general knowledge test, an introduction to the disease, and a demonstration of the CD. This lecture was followed a week later by a session in the computer laboratory, where fourth-year students ran through the CD for 25 min, after which they completed a computer-based test with the same questions as the previous week. Students, who were unaware that the questions would be the same received immediate feedback on their performance after completion of this second test. For logistical reasons, third-year students were not tested for a second time. The results of the first test and answers to questions were not discussed with students before they took the second test.

As indicated in Table I, there was a remarkable improvement of their knowledge of HIV/AIDS as captured by the test questions (see Appendix). The fourth-year test mean $(\mu)$ improved from 39.1 to 71.1%, indicating the potential of the CD to satisfy one of its major goals, i.e., to promote an understanding of the disease among the student population at the University of Pretoria. The results of the first test indicate no significant difference in the test scores of third- and fourth-year students.

## III. HIV/AIDS MATHEMATICAL MODEL

The simplest HIV/AIDS mathematical model can best be understood through the interactions of healthy CD4+ cells, infected CD4+ cells, and free viruses, as described in Fig. 1 [3]. (HIV largely exerts its effect on the immune system by destroying CD4+ T cells that are critical in helping the body fight infections. *Free virus* refers to the HI virus found in the blood plasma.)

Fig. 1 describes the interaction of three variables: the healthy CD4+ cells, the infected CD4+ cells, and the free virus. The healthy CD4+ cells are produced from a source, such as the thymus at a constant rate $s$ and die at a rate $d$. They are infected by the virus at a rate that is proportional to the product of their abundance and the amount of free-virus particles. The proportionality constant $\beta$ is an indication of the effectiveness of the infection process. The infected CD4+ cells result from the infection of healthy CD4+ cells and die at a rate $\mu_2$. Free-virus particles, which are also known as virions, are produced from infected CD4+ cells. These free-virus particles are cleared at a rate $\mu_1$.

The interactions described previously can be summarized in differential equations

$$\frac{dT}{dt} = s - dT - \beta Tv$$
$$\frac{dT^*}{dt} = \beta Tv - \mu_2 T^*$$

and

$$\frac{dv}{dt} = kT^* - \mu_1 v \tag{1}$$

where $T$ represents the abundance of healthy CD4+ cells; $T^*$, the abundance of infected CD4+ cells; and $v$, the abundance of free viruses. The parameters and their typical values are listed in Table II.

For the parameter values in Table II, a typical disease progression can be simulated, as shown in Fig. 2. It shows the time evolution of healthy CD4+ cells (graph 1), infected CD4+ cells (graph 2), and the number of free viruses (graph 3) from the time of infection up to the asymptotic stage, i.e., a period of 1000 d. The third graph, which depicts the virus dynamics, shows that when there is an initial infection, the abundance of infected cells increases (as can be seen from graph 2), and the number of healthy CD4+ cells reduces. The presence of the virus activates the human immune system to kill some of the invading viruses, therefore reducing the number of infected cells. As a result of this immune defense, the healthy CD4+ cells increase in number. Eventually a "set point," or asymptotic stage, is reached.

More complex models provide a deeper understanding of the disease through, among others, the inclusion of latently infected CD4+ cells. The basic HIV/AIDS model (1) has been used in [3] to estimate parameters $\mu_1$ and $\mu_2$, which are key indicators of the disease in infected persons. The impact of an individual's

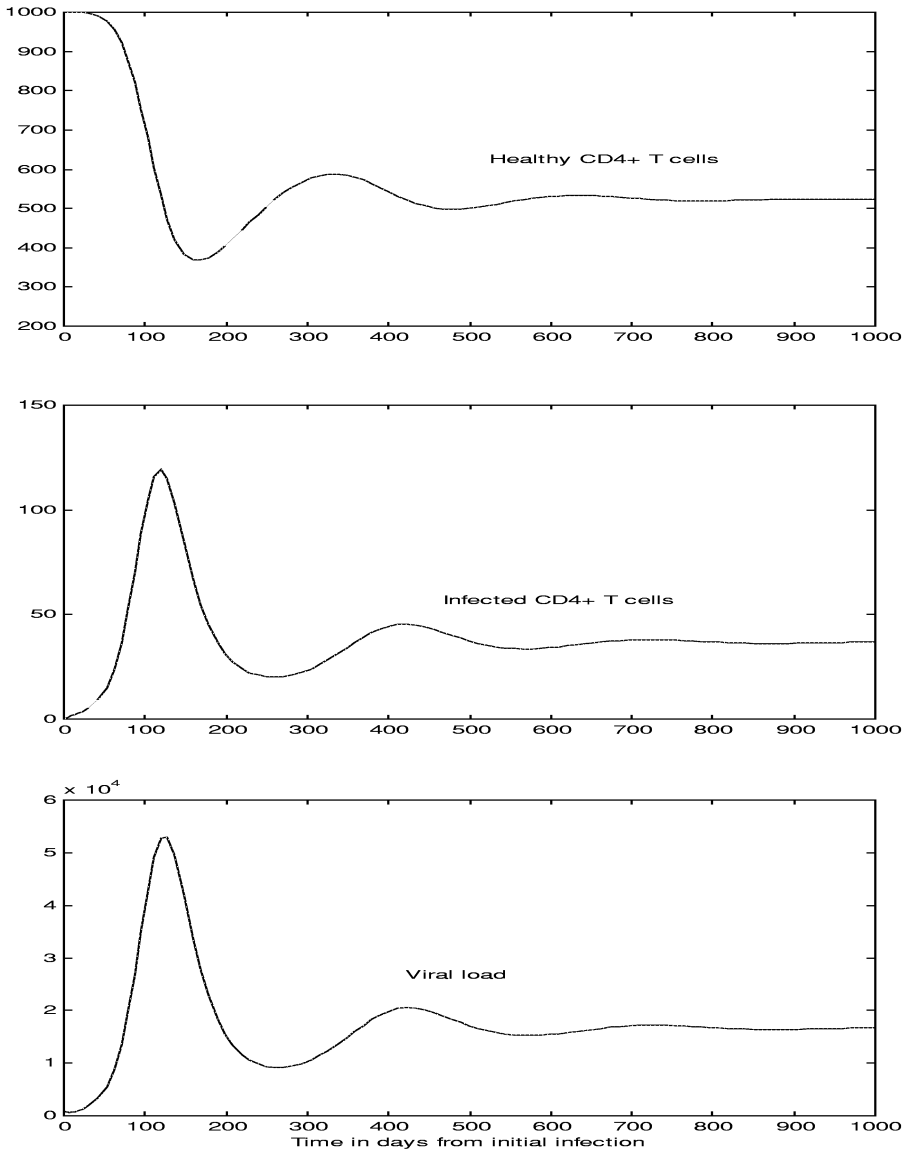


Fig. 2. Time simulation of the progression of the HIV disease (viral load—virus copies per milliliter of plasma; CD4+ T cells—number of healthy/infected cells per milliliter of plasma).

parameter variations on the effectiveness of HIV chemotherapy is a topic of current investigation [4], [7].

## IV. Control Systems and HIV/AIDS Education

The HIV/AIDS model described in Section III has been introduced into a third-year control systems course offered by the the Department of Electrical, Electronic, and Computer Engineering at the University of Pretoria [8], complementing the text by Goodwin *et al.* [9] that is prescribed for this course. The HIV/AIDS model is used to illustrate standard material such as linearization around an equilibrium, system stability, feedback, and dynamic compensation. The purpose of this illustration is to relate these basic control systems' engineering concepts that the students are learning to the infection, progression, and chemotherapy treatment of the disease. The CD described in Section II provides the background material required to understand the model, as well as the model itself, in Java applet form.

### *A. Equilibrium, Linearization, Stability, and HIV Infection and Progression*

The system (1) has two equilibrium points, obtained by setting the right-hand sides of the equations in (1) to zero, as follows:

$$\left(\frac{s}{d}, 0, 0\right) \tag{2}$$

and

$$\left(\frac{\mu_1\mu_2}{\beta k}, \frac{s}{\mu_2} - \frac{d\mu_1}{\beta k}, \frac{ks}{\mu_1\mu_2} - \frac{d}{\beta}\right). \tag{3}$$

Let

$$R_0 = \frac{\beta s k}{d\mu_1\mu_2}.$$

Using an indirect Lyapunov analysis [10], several conclusions can be drawn.

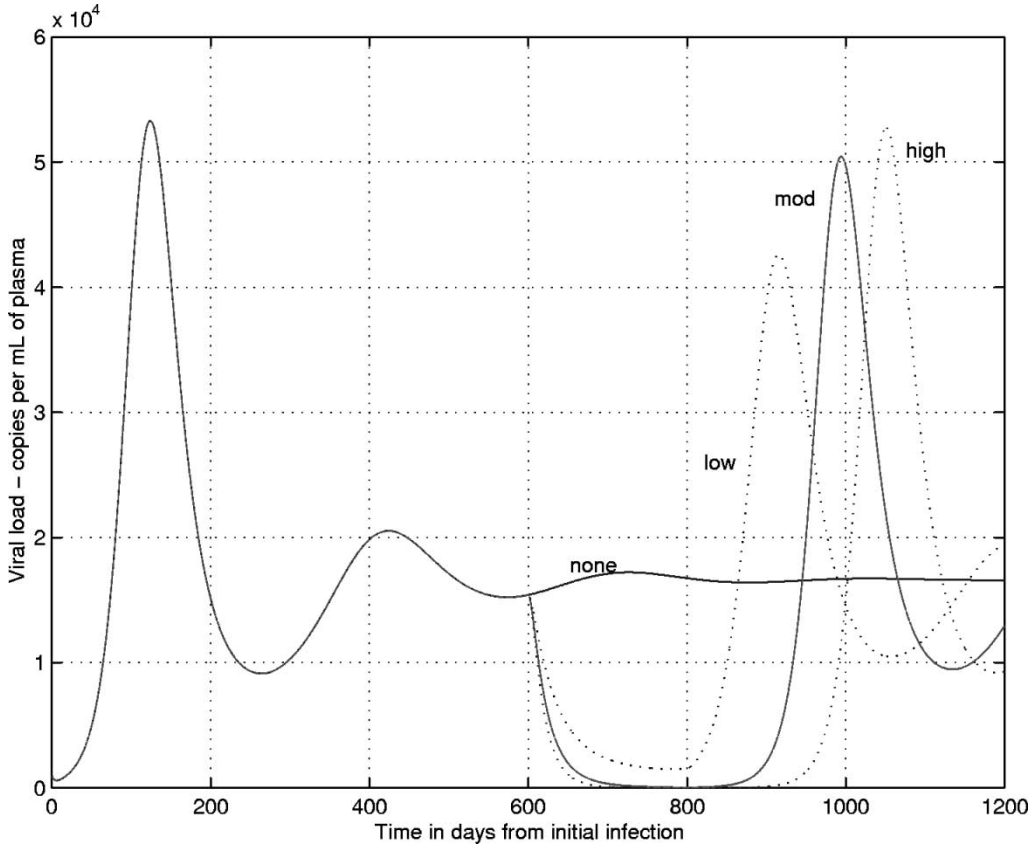


Fig. 3. RT therapy from day 600 to day 800 (viral load—virus copies per milliliter of plasma).

1) If $R_0 < 1$, the equilibrium (2) is locally asymptotically stable. Thus, the virus will not spread.
2) If $R_0 > 1$, the equilibrium (2) is unstable, but the equilibrium (3) is locally asymptotically stable. The virus will spread after infection, and the abundance of uninfected cells, infected cells, and free viruses at the new equilibrium is given by (3). This situation is depicted in Fig. 2.

A Lyapunov analysis, as described previously, is too advanced for an introductory control course; hence, an eigenvalue analysis of the linearized HIV model is performed instead, as discussed in subsection C.

### *B. Control and Chemotherapy Treatment*

Two major categories of antiretroviral drugs to combat HIV are reverse transcriptase inhibitors (RTIs) and protease inhibitors (PIs). One approach to reflect the effect of RTIs in the model is based on the interpretation that a RTI reduces infection of new cells but does not block production of viruses from cells already infected and past the stage at which reverse transcription occurs [11]. If one excludes modeling of drug pharmacokinetics or metabolic variations, RTI treatment can be modeled as a constant reduction of various viral rates during the time of treatment, and the resistance is taken as the re-rise of viral rates after a period of treatment. (Note that HIV is "resistant" to an antiviral medication if it keeps multiplying while the drug is being taken. Changes (mutations) in the virus cause resistance.)

$\beta$ is taken as the RTI control variable. Confirmation for this interpretation of the effect that RTIs has on the progression of HIV is given in [11]–[13]. Similarly, the effect of PIs is lumped into the parameter $k$ in model (1). Descriptions of the prevailing usage and combination of drugs in medical practice can be found in [11]–[13].

The model given in (1) can be rewritten to accommodate control actions or chemotherapy treatment as

$$\frac{dT}{dt} = s - dT - (1-u_1)\beta T v$$
$$\frac{dT^*}{dt} = (1-u_1)\beta T v - \mu_2 T^*$$

and

$$\frac{dv}{dt} = (1-u_2)kT^* - \mu_1 v \tag{4}$$

in which $u_1$ and $u_2$ represent the efficacy of the two types of drugs, i.e., they are unitless real numbers between 0 and 1. A single application of an RTI then corresponds to making $u_2 = 0$ and varying $u_1$ such that $0 \leq u_1 \leq 1$.

Students can test different RTI dosage designs in the Matlab/Simulink environment by simulating the effects of:

1) the time at which therapy is initiated;
2) the time at which therapy is terminated;
3) the strength of the dosage: strong, medium, or weak.

These simulations can then be compared to the Java applet simulations that they performed on the CD described in Section II. Fig. 3 shows the virus response when therapy is

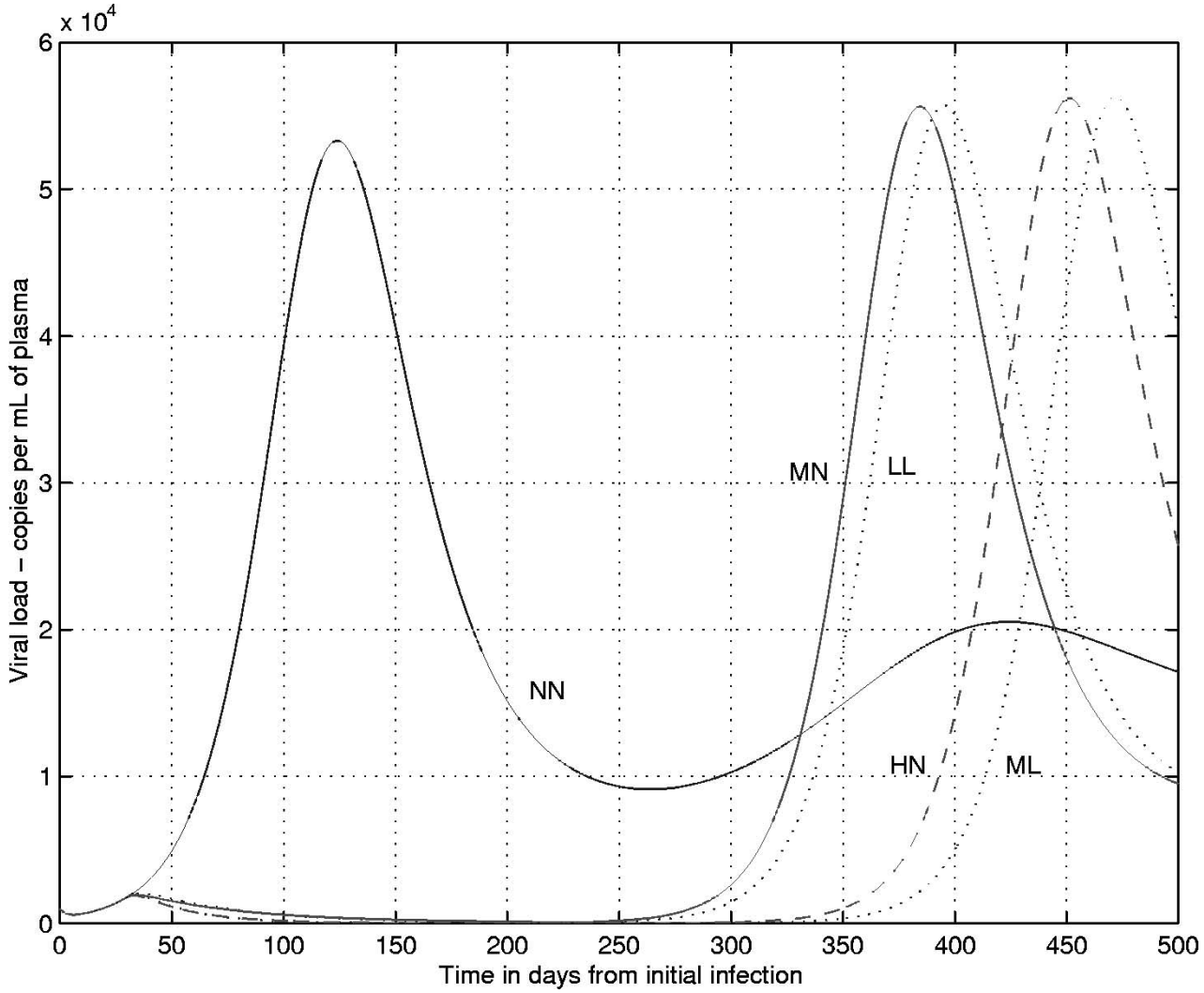


Fig. 4. Mismatched therapy from day 30 to day 250 (viral load—virus copies per milliliter of plasma).

initiated at day 600 and terminated at day 800. The dotted line indicates a high dosage; the solid line, a moderate dosage; and the dashed line, a low dosage. This figure illustrates the effectiveness with which RTIs suppresses the viral load. For a stronger dosage, the viral load is suppressed longer but bounces back higher after the therapy is terminated.

Combined therapy (using RTIs and PIs) corresponds to the case where $u_1$ and $u_2$ vary between 0 and 1, and the effect is illustrated in Fig. 4. The first letter of the graph labels refers to the RTI, and the second, to the PI. N, L, M, and H indicate no, low, moderate, and high dosages, respectively. For example, ML refers to a moderate RTI dosage combined with a low RI dosage.

Combination therapy using mismatched dosages has some interesting outcomes. Fig. 4 shows that using a combined low and moderate-dose therapy can be better for reducing the viral load than using a single high-dose therapy. Low-efficacy drugs can, therefore, be used to augment the performance of other drugs with higher efficacies. In fact, a combination of low-efficacy drugs can be taken together in the situation when the more expensive drugs, used in highly active antiretroviral therapy (HAART), are not affordable or available.

### C. Student Project

The model (4) is highly nonlinear and has two inputs, which generally would make it ill-suited for use in a typical introductory control systems course where the focus is on the analysis and design of controllers for linear time-invariant and single-input–single-output systems. However, by using only one control input (single therapy treatment) and studying a linear approximation of model (4) around a suitable operating point, students can obtain valuable qualitative and quantitative insights into the interactions between HIV and the immune system. In addition, such a model can also demonstrate the major concepts of control systems engineering [14], i.e., dynamic systems, stability, feedback, and dynamic compensation, as described in this section.

Taking RTI as the only antiretroviral agent, the system (4) becomes single input, and the linearization around the operating point ($T_0$, $T_0^*$, and $v_0$) (with $u_{10} = 0$) has the following state transition matrix $A$ and input matrix $B$:

$$A = \begin{bmatrix} -d - \beta v_0 & 0 & -\beta T_0 \\ \beta v_0 & -\mu_2 & \beta T_0 \\ 0 & k & -\mu_1 \end{bmatrix}, \quad B = \begin{bmatrix} \beta T_0 v_0 \\ -\beta T_0 v_0 \\ 0 \end{bmatrix}. \quad (5)$$

**HIV / AIDS general knowledge test (Memorandum)**

**NB:** More than one answer may be correct

**Question 1:**
In which year were the first signs of this fatal new illness (that later became known as AIDS) seen in the United States of America?
a) 1975 b) 1981 c) 1984 d) 1991

**Question 2:**
In which of the following regions was the HIV epidemic last to develop?
a) East Asia b) Latin America c) Southern Africa

**Question 3:**
Which of the following regions in the world has the smallest HIV positive population?
a) Australia and New Zealand b) East Asia c) North America d) Western Europe

**Question 4:**
Approximately how many adults and children were estimated to be living with HIV/AIDS in Sub-Saharan Africa at the end of 2001?
a) 250 000 b) 560 000 c) 16 million d) 28 million e) 39 million

**Question 5:**
Which of the following body fluids contain sufficient quantities of the virus to be infectious?
a) blood b) breast milk c) saliva d) semen
e) sweat f) tears g) urine h) vaginal secretions/fluid

**Question 6:**
Which of the following is the most common ways in which HIV is transmitted?
a) Coming in contact with body fluids of an HIV positive person
b) Mother- to- child transmission through breast feeding
c) Sharing needles or syringes
d) Transmission from patient to health care worker or vice-versa
e) Unprotected penetrative sexual contact

**Question 7:**
Which one of the following is the most effective way to reduce the risk of contacting HIV?
f) condoms
g) monogamous relationships
h) oral sex
i) vaccines

**Question 8:**
Which of the following statements are true?
a) After a person experience initial flu-like symptoms, an average of 5 to 7 years will pass without another sign of infection.
b) AIDS is a synonym for HIV
c) HIV infection is a death sentence
d) STI's (Sexually transmitted infections) serve as avenues for HIV to enter the bloodstream

**Question 9:**
Which of the following statements is true regarding the results of an HIV test?
a) A negative result after six weeks indicates no infection
b) During the widow period the virus is present in the body, but it is not detectable by antibody tests
c) If the virus is present it is always detectable

Fig. 5. HIV/AIDS General Knowledge Test.

With the typical parameter values given in Table II, the pair $(A, B)$ is, at operating point (2) (which is now (500,0,0))

$$A_1 = \begin{bmatrix} -0.02 & 0 & -0.012 \\ 0 & -0.24 & 0.012 \\ 0 & 100 & -2.4 \end{bmatrix}, \quad B_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \tag{6}$$

and at operating point (3) (which is now (240.00, 21.67,902.78))

$$A_2 = \begin{bmatrix} -0.0417 & 0 & -0.0058 \\ 0.0217 & -0.24 & 0.0058 \\ 0 & 100 & -2.4 \end{bmatrix}, \quad B_2 = \begin{bmatrix} 5.2 \\ -5.2 \\ 0 \end{bmatrix}. \tag{7}$$

**Question 10:**
Which of the following statements is true regarding a HIV positive person who does not show symptoms?
a) He / she cannot infect anybody
b) The virus is inactive
c) The virus is still multiplying in their body

**Question 11:**
Match the following:

| | | | |
|---|---|---|---|
| 11.1 | Mono-therapy (treatment with only one agent such as AZT or Nevirapine) | a) | Is used to prevent HIV from changing its chemical (or genetic) structure to inhibit the virus's resistance to drugs. |
| 11.2 | **Anti-retroviral therapy (ART)** | b) | Only used to limit the vertical transmission of HIV from mother to child |
| | | c) | **Is used to reduce the viral load as much as possible for as long as possible** |

**Question 12:**
Which of the following side effects are commonly associated with anti-retroviral drugs?
a) Abnormal distribution of body fat b) Infertility c) Nausea d) Skin irritation

**Question 13:**
Which of the following STI's (Sexually transmitted diseases) can appear again when a person is stressed or ill?
a) Gonorrhea b) Herpes c) Hepatitis B d) Syphilis

**Question 14:**
Which of the following STI's (Sexually transmitted diseases) can lead to death or liver cancer?
a) Gonorrhea b) Herpes c) Hepatitis B d) Syphilis

**Question 15:**
Which of the following statements are true regarding CD4 cells?
a) A person is said to have AIDS when the CD4 cell count drops to 500 and below
b) Critical cells, which help the body, fight infections
c) Normal CD4 cell count ranges from 600 – 2000 cells/mm3

**Question 16:**
Which of the following statements is true regarding a person's viral load?
a) A higher viral load may lead to a greater chance that mutant HIV will arise, which is resistant to medication.
b) The lower the viral load, the more rapidly a person's immune system will be damaged by CD4 cell destruction.
c) Viral load is a measurement of the CD4 count in a person's body.

**Question 17:**
Which of the following are requirements for HIV infection to occur?
a) Access point into the body
b) Being in the window period
c) Suffering from an opportunistic infection
d) Sufficient quantities of the virus

Fig. 5. (*Continued.*) HIV/AIDS General Knowledge Test.

The three eigenvalues of $A_1$ (6) are $(-0.02,\ 0.2183,\ -2.8583)$. Since $A_1$ has a positive eigenvalue, the system is not stable at the operating point (2). The three eigenvalues of $A_2$ (7) are $(-0.0199 + 0.6658\text{i},\ -0.0199 - 0.6658\text{i},\ -2.6418)$, and since all eigenvalues have negative real parts, the system is stable at operating point (3).

At the operating point (2), the matrix $B$ is zero; therefore, the input variable does not enter linearly. Even though controllability of linear systems is not covered in this third-year course, students are expected to understand that a linear analysis of the system cannot effectively be applied to the operating point (2).

The operating point (3) corresponds to the asymptomatic stage of an HIV patient. A typical control action (treatment) during this stage is to bring the viral load down to a lower level. Students are requested to do both open-loop and closed-loop control for this purpose, using the linear model. Open-loop-control design requires finding a fixed input value (fixed dosage) so that the viral response takes on a certain shape in terms of rise time and settling time. Medically, a successful retroviral therapy is designed to reduce the viral load by 90% in eight weeks and continue to suppress it to below 50 virus copies per milliliter of blood plasma in 6 mo.

In addition, students are expected to design a closed-loop PID controller and to demonstrate its disturbance attenuation capabilities. A typical disturbance can be an extra term added to the first equation of (4), representing immune system fluctuation or the immunal effect of a coinfection. This forms part of a semester project that was given to students during the second semester of 2002 (July–October 2002). The project consists of the following subsections.

- Find the transfer function corresponding to (7) if the output is the viral load, i.e., $y = v$.
- Set the specification for the viral response in terms of rise time and settling time.
- Find an input value $u_1$ to meet the chosen specification.
- Use a frequency response method to design a PID controller to meet the above specification.
- Compare the response of open-loop control and closed-loop PID control in the presence of a disturbance. Discuss the disturbance rejection capabilities of a PID controller.

## V. Conclusion

This paper describes the introduction of HIV/AIDS education into the curriculum of the Department of Electrical, Electronic, and Computer Engineering at the University of Pretoria, South Africa. Third- and fourth-year students were provided with an HIV/AIDS educational CD developed at the University of Pretoria. Their knowledge of the subject was tested via two quizzes—one written before they were exposed to the material on the CD, and one after. The results of these quizzes suggest a marked improvement in the general understanding that students have of HIV/AIDS.

In addition, a mathematical HIV/AIDS model is being introduced into an introductory third-year control systems course. This model is used to illustrate engineering concepts of standard control systems, such as linearization, system stability, feedback, and dynamic compensation. Students are asked to linearize the HIV/AIDS model around a suitable operating point, to do a stability analysis of the resulting system, to set specifications for the viral load, and to develop open- and closed-loop strategies to achieve such specifications in the face of output disturbances.

## Appendix
## HIV/AIDS General Knowledge Test

The HIV/AIDS General Knowledge Test is presented in Fig. 5.

## Acknowledgment

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## References

[1] (2002, Sept.) AIDS Epidemic Update, Dec. 2001. [Online] Available: http://www.unaids.org/epidemic_update/report_dec01/
[2] HIV/AIDS Educational CD, University of Pretoria, Pretoria, South Africa, 2002.
[3] M. A. Nowak and R. M. May, *Virus Dynamics: Mathematical Principles of Immunology and Virology*. New York: Oxford Univ. Press, 2000.
[4] M. Jeffrey, X. Xia, and I. K. Craig, "Controllability analysis of the chemotherapy of HIV," in *Proc. 15th IFAC World Congr.*, Barcelona, Spain, July 2002.
[5] X. Xia, "Estimation of HIV/AIDS parameters," in *Proc. 15th IFAC World Congr.*, Barcelona, Spain, July 2002.
[6] *HIV/AIDS in South Africa 2002*. Pretoria, South Africa: Centre for the Study of AIDS—University of Pretoria, 2002.
[7] "Special issue on HIV/AIDS research in South Africa," *South African J. Sci.*, vol. 96, no. 6, June 2000.
[8] M. Braae, E. Boje, I. K. Craig, P. L. De Vaal, J. Gouws, S. G. Mclaren, C. L. E. Swartz, C. P. Ungerer, J. L. Van Niekerk, and B. Wigdorowitz, "Special issues on control education: South Africa," *IEEE Control Syst. Mag.*, vol. 16, pp. 41–47, Apr. 1996.
[9] G. C. Goodwin, S. F. Graebe, and M. E. Salgado, *Control System Design*. Englewood Cliffs, NJ: Prentice-Hall, 2001.
[10] M. Vidyasagar, *Nonlinear Systems Analysis*. Englewood Cliffs, NJ: Prentice-Hall, 1978, p. 186.
[11] M. A. Nowak and S. Bonhoeffer, "Scientific correspondence," *Science*, vol. 375, p. 193, 1995.
[12] A. S. Perelson and P. W. Nelson, "Mathematical analysis of HIV-1 dynamics in vivo," *SIAM Rev.*, vol. 41, pp. 3–44, 1999.
[13] J. A. M. F. de Souza, M. A. L. Caetano, and T. Yoneyama, "Optimal control theory applied to the anti-viral treatment of AIDS," presented at the IEEE Conf. Decision Control, Sydney, Australia, 2000.
[14] N. A. Kheir, K. J. Åström, D. Auslander, G. F. Cheok, G. F. Franklin, M. Masten, and M. Rabins, "Control system engineering education," *Automatica*, vol. 32, pp. 147–166, Feb. 1996.

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