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Control Design for Preventing Dengue Infections using Input-Output Linearization Method

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Abstract. This study deals with a theoretical study of control design to prevent transmission of dengue fever viruses. The input-output linearization method is a feedback control method that can be applied to design the control functions so that the transmission of dengue viruses can be disrupted. Fogging is considered as an eradication effort and vaccination is considered as a prevention effort. Both treatments are considered as the input controls of the method while infected human variable is considered as the output control. By treating eradication effort and prevention effort as the control inputs we design controls that can stabilize the system and lead the infected population going to zero. Some numerical schemes are presented to confirm the theoretical results and the analytical results.

1. Introduction

Infectious diseases such as dengue fever are mainly found in tropical and subtropical regions such as Indonesia. From 1968 to 2009, the World Health Organization (WHO) records that Indonesia is a country with the highest cases of dengue fever in Southeast Asia where the first case was found in Surabaya at 1968 [1]. Since the disease can cause organ damage even death, early treatment should be arranged to reduce the mortality rate caused by this disease.

Mathematical modelling is one of the powerful tools to study dengue fever problem especially to analyse different strategies that might be useful in controlling the disease. This theoretical approach can help us to understand the transmission dynamics of the viruses that can involve human and mosquito population. Various mathematical modelling and mathematical theory have been formulated and developed to study the transmission of dengue viruses in human and mosquito populations. For instance Nuraini et al., 2009 [2] and Chávez et al., 2017 [3] that examined mathematical model of dengue to identify main factors that influence the spread of the disease; Diekmann et al. [4] and Driessche & Watmough [5] that developed mathematical tools called the next generation matrix and basic reproduction number to quantify the multiplication factor of the primary infectious cases to be the secondary infectious cases. Some researchers also combined mathematical model with optimal control theory to study effects of controls such as vaccination, space spraying, and treatment cycle in reducing infectious both in human and mosquito populations [6-10]. In this research we also study the transmission of dengue viruses by combining mathematical model of the disease with the input-output linearization method to observe the dynamics of the system before and after control. This study will give another point of view regarding control study of the transmission of dengue viruses such that strategies can be identified to overcome the outbreak of disease.

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This paper is organized as follow. In Section 1, we present an introduction about dengue fever and some mathematical models about this disease. In Section 2 we present derivation of linear control using input-output linearization method and in the last section we present some numerical simulations and discussion about the simulation results.

2. Control Design Using Input-Output Linearization Method

Before deriving the input control, firstly let us consider the formulation of the mathematical model of dengue disease. Formulating the mathematical model of the spread of dengue infections involves the interactions of two population, i.e. human population and mosquitos' population. The two populations have an important role in the spread of dengue viruses. In the previous study, Ningsih (2017) [10] has formulated the mathematical model for dengue by considering an integrated vector control for reducing the transmission of dengue. It assumed that the integrated vector control for reducing the transmission viruses is a combination of vaccination for susceptible human and fogging for mosquito population. By using the similar model, we have the following dimensionless system [10],

$$\dot{\mathbf{x}}(t)=\begin{bmatrix} \mu_h-\left(B\beta_{mh}\dfrac{N_m}{N_h}x_6(1-u_1)+\mu_h\right)x_1+\theta x_3 \\ B\beta_{mh}\dfrac{N_m}{N_h}x_1x_6(1-u_1)-(\eta_h+\mu_h)x_2 \\ \eta_h x_2-(\theta+\mu_h)x_3 \\ \varphi\left(1-\dfrac{N_m}{kN_h}x_4\right)(x_5+x_6)-(\eta_A+\mu_A)x_4 \\ \eta_A x_4-(B\beta_{hm}x_2+\mu_m+u_2)x_5 \\ B\beta_{hm}x_2x_5-(\mu_m+u_2)x_6 \end{bmatrix}, \tag{1}$$

Table 1. Variables and parameters of the model (1).

Parameter	Description	Value	Ref.
$1/\mu_h$	average lifespan of humans (days)	$71 * 365$	[6]
N_h	total of human population	48000	Assumed
N_m	total of mosquito population	500000	Assumed
B	average number of bites on humans by mosquitoes, per day	0.8	[6]
β_{mh}	transmission probability from infected human (per bite)	0.35	[6]
β_{hm}	transmission probability from infected mosquito (per bite)	0.375	[6]
θ	decreasing rate of human immunity per day	0.05	Assumed
$1/\eta_h$	mean of viremia period (in days)	3	[6]
η_A	maturation rate from larvae to adult (per day)	0.08	[6]
φ	number of eggs at each deposit per capita (per day)	10	Assumed
k	number of dismissed larvae per human	6	Assumed
$1/\mu_A$	natural mortality of larvae (in day)	4	[6]
$1/\mu_m$	average lifespan of adult mosquitoes (in days)	10	[6]

where $\boldsymbol{x_1(t)}$ represents the proportion of susceptible humans at time t, $\boldsymbol{x_2(t)}$ is the proportion of infected humans with dengue virus at time t, $\boldsymbol{x_3(t)}$ is the proportion of humans recovered from dengue hemorrhagic fever at time t, $\boldsymbol{x_4(t)}$ is the proportion of mosquitoes in the water phase including eggs,