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Estimation of Thrombocyte Concentrate (TC) and *Whole Blood* (WB) using Unscented Kalman Filter

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Abstract

As the need for blood transfusion increases, an improved blood stock management for blood transfusion is required. In terms of quality and quantity, blood transfusion is needed by patients with various health problems. Because of that need, it is urgent that the stability of blood stock be maintained to avoid possible excessive blood stock that leads to unnecessary blood disposal. For that purpose, prediction of blood demand is required. One of the blood transfusion units is PMI, a national organization dealing with social concern and humanity field. The objective of this paper is to make estimation of blood demand for Whole Blood (WB) and Thrombocyte Concentrate (TC) using Unscented Kalman Filter method. The simulation results show that the UKF method is effective with a high accuracy and an error of less than 3.5%.

Keyword: *Whole Blood, Thrombocyte Concentrate, Estimation, Unscented Kalman Filter*

Introduction

Blood is an important component in the body that carries nutrients and oxygen to all organs of the body, including vital organs such as the brain, heart, kidneys, lungs, and liver. If there is a lack of blood in the body caused by several things, the nutritional and oxygen requirements of these organs cannot be fulfilled. Tissue damage can occur quickly which leads to death. To prevent this, a blood supply from outside the body is needed. The process of transferring blood from a healthy person (donor) to a sick person / needy (recipient) is called a blood transfusion [1]. Blood transfusion has become an important part of health care. If blood transfusions are applied correctly, transfusion can save the lives of patients and can improve the health status of these patients.

During this current co-19 pandemic, it is necessary to estimate blood supply to support hospitals treating patients in hospitals. Using blood supply estimation software, blood bank or hospitals can predict the amount of available inventory so that if there is a shortage of supplies, the blood bank is ready for any possible anticipations.

Estimation of the number of requests is required in the health field. Blood is very important in human life. Blood is a liquid in the body, needed to transport oxygen needed by cells throughout the body [2]. To minimize errror, an effort shall be made by estimating the number of requests for blood at the Indonesian Red Cross (PMI). Estimation is required as a problem can often be solved by using previous information or data related to the problem [4,5,6]. One estimation method is EKF functioning to minimize covarience error in correction step [7]. In this paper, the estimation of the demand for Whole Blood (WB) and Thrombocyte Concentrate (TC) blood. The development of the Kalman Filter method is the Unscented Kalman Filter (UKF) obtained by applying sigma point at the prediction stage. In this paper, UKF method was applied to estimate the demand for WB dan TC blood as the basis of the consideration of the blood bank management.

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Blood Data of *Whole Blood* (WB) and Thrombocyte Concentrate (TC)

The data of Whole Blood (WB) and Thrombocyte Concentrate (TC) is shown as follows:

Table 1. Blood Data of WB type

Data of WB												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2013	1018	1062	1083	1076	1222	1053	1007	1031	1039	1023	979	1052
2014	1103	953	972	812	872	906	871	1085	897	859	818	744
2015	890	865	911	797	787	687	643	801	730	686	666	723
2016	803	659	653	629	666	599	595	576	629	557	500	504
2017	579	611	675	583	637	488	647	684	581	715	749	612
2018	688	679	640	591	725	759	622	730	676	666	675	599
2019	712	753	709	682	688	703	690	720	719	698	711	701

Tabel 2 Blood Data of TC type

Data TC												
	Jan	**Feb**	**Mar**	**April**	**Mei**	**Juni**	**Juli**	**Agust**	**Sep**	**Okt**	**Nov**	**Des**
2013	2518	2331	2336	2280	2362	1609	1626	1879	1139	1585	1648	1544
2014	1695	1286	1440	1398	1473	1612	1470	1500	1799	1661	1244	1584
2015	2534	2501	2055	2249	1898	1910	1605	1395	1441	1429	1405	1564
2016	1948	1944	1904	2069	2243	1815	1654	1670	1517	1779	1364	1575
2017	1622	1390	1887	1112	1326	1255	1172	1487	1417	1394	1638	1531
2018	1650	1441	1429	1405	1586	1292	1172	1487	1417	1394	1638	1531
2019	1520	1378	1422	1311	1493	1488	1512	1531	1392	1347	1583	1536

Unscented Kalman Filter

Algorithm of Unscented Kalman Filter is writen as follows [7]:

- *Initiation at $k = 0$*:

$$\hat{x}_0 = E[x_0]$$
$$P_{x_0} = E[(x_0 - \hat{x}_0)(x_0 - \hat{x}_0)^T]$$
$$\hat{x}_0^a = E[x^a] = E\left[\hat{x}_0^{\,T} \;\; 0 \;\; 0\right]^T$$
$$P_0^a = E[(x_0^a - \hat{x}_0)(x_0^a - \hat{x}_0)^T] = \begin{bmatrix} P_x & 0 & 0 \\ 0 & P_v & 0 \\ 0 & 0 & P_n \end{bmatrix} \quad (1)$$

For $k = 1,2,3,\ldots,\infty$:

1) Count sigma point

$$X_{k-1}^a = \left[\hat{x}_{k-1}^a \quad \hat{x}_{k-1}^a + \gamma\sqrt{P_{k-1}} \quad \hat{x}_{k-1}^a - \gamma\sqrt{P_{k-1}}\right]$$

Dimana:

$$\gamma = \sqrt{L + \lambda}$$
$$\lambda = \alpha^2(L + \kappa) - L \quad (2)$$

2) Time-update (prediction stage)

$$X_{k|k-1}^x = f(X_{k-1}^x, X_{k-1}^v)$$
$$\hat{x}_k^- = \sum_{i=0}^{2L} W_i^{(m)} X_{i,k|k-1}^x$$

$$P_{x_k}^- = \sum_{i=0}^{2L} W_i^{(c)} \left(X_{i,k|k-1}^x - \hat{x}_k^-\right) \left(X_{i,k|k-1}^x - \hat{x}_k^-\right)^T$$
$$Z_{k|k-1} = H(X_{k|k-1}^x, X_{k-1}^n)$$
$$\hat{z}_k^- = \sum_{i=0}^{2L} W_i^{(m)} Z_{i,k|k-1} \qquad (3)$$

3) Measurement update (cortrection stage):

$$P_{\bar{z}_k,\bar{z}_k} = \sum_{i=0}^{2L} W_i^{(c)} \left(Z_{i,k|k-1} - \hat{z}_k^-\right) \left(Z_{i,k|k-1} - \hat{z}_k^-\right)^T$$
$$P_{x_k,z_k} = \sum_{i=0}^{2L} W_i^{(c)} \left(X_{i,k|k-1}^x - \hat{x}_k^-\right) \left(Z_{i,k|k-1} - \hat{z}_k^-\right)^T$$
$$K_k = P_{x_k,z_k} P_{\bar{z}_k,\bar{z}_k}^{-1}$$
$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - \hat{z}_k^-)$$
$$P_{x_k} = P_{x_k}^- - K_k P_{\bar{z}_k} \mathrm{K}_k^T \qquad (4)$$

Discussion and Analysis

From the blood data of WB and TC types in Table 1 and 2, a mathematical function was obtained for the blood supply of WB and TC types using Mathematica software. The Mathematica software simulation resulted in a function of WB and TC as follows:

$$f_{wb}(x) = 1025.13 - 1.3789x - 0.371\, x^2$$
$$f_{wb}'(x) = -1.3789 - 0.742\, x \qquad (5)$$
$$f_{tc}(x) = 1548 - 3{,}137x + 0.869\, x^2$$
$$f_{tc}'(x) = -3{,}128 + 1{,}738\, x \qquad (6)$$

from equations (2), the modified WB and TC blood stock function model in (5) and (6) is discreted using the finite difference method and obtained as follows:

$$f_{wb_{k+1}} = (-1.3789 - 0.742\ \ x_k)\Delta t$$
$$f_{tc_{k+1}} = (-3{,}128 + 1{,}7382\ \ x_k)\Delta t$$

After the function was got, then it was computation simulated with the Matlab software. In this paper a simulation was applied by applying the Unscented Kalman Filter (UKF) algorithm to the function of blood stock of Whole Blood (WB) and Thrombocyte Concentrate (TC) type. The simulation results were evaluated by comparing the real conditions in the field with the estimation results of UKF. This simulation used $\Delta t = 0{,}1$ and 100, 200, and 300 iteration. Figure 1-3 is the Whole Blood (WB) stock estimation results using UKF methods using 100, 200 and 300 iteration. Figure 4-6 is the Thrombocyte Concentrate (TC) stock estimation results using UKF methods using 100, 200 and 300 iteration

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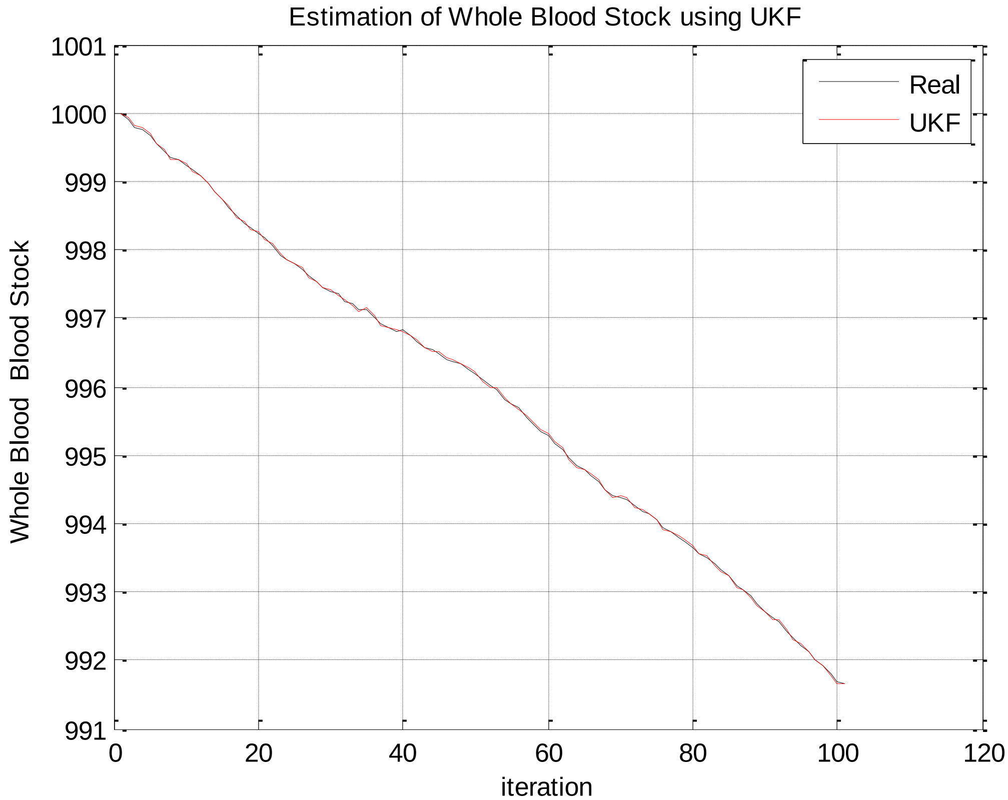

Figure 1. Estimation of WB blood using UKF methods with 100 iteration

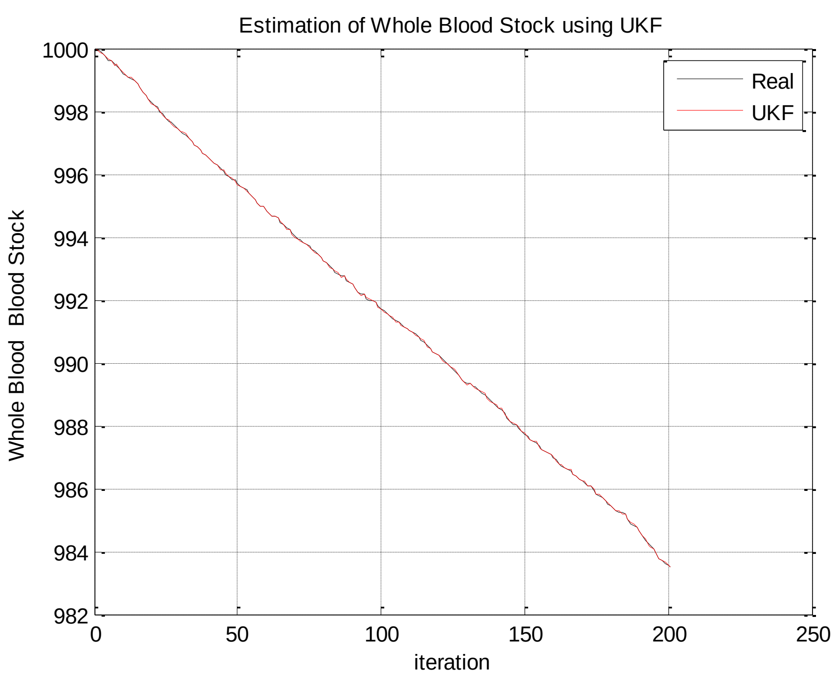

Figure 2. Estimation of WB blood using UKF methods with 200 iteration

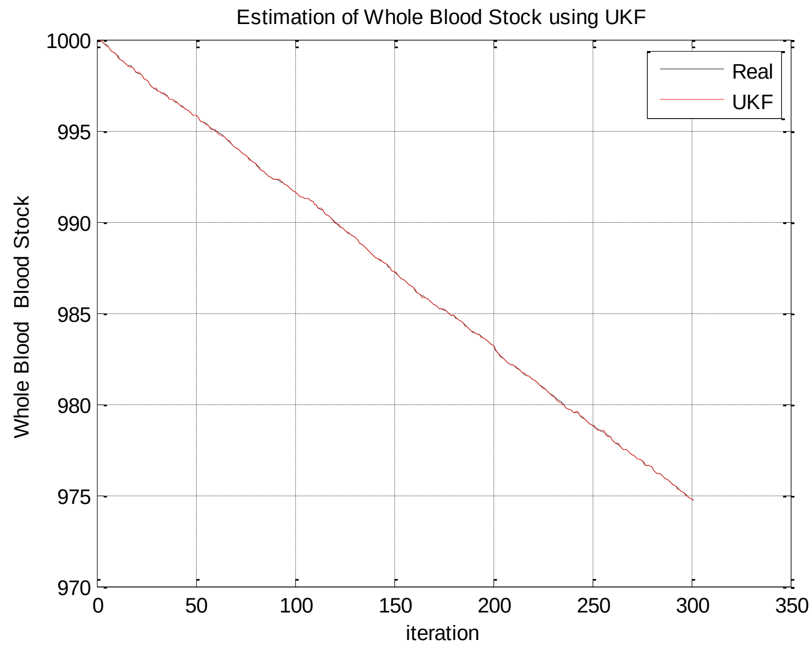

Figure 3. Estimation of WB blood using UKF methods with 300 iteration

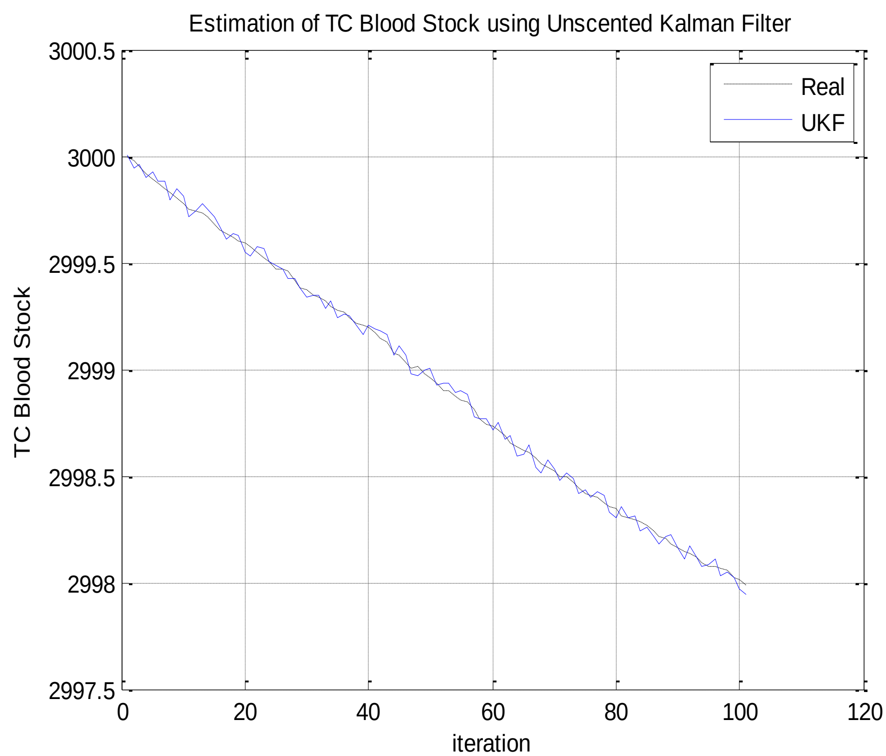

Figure 4. Estimation of TC blood using UKF methods with 100 iteration

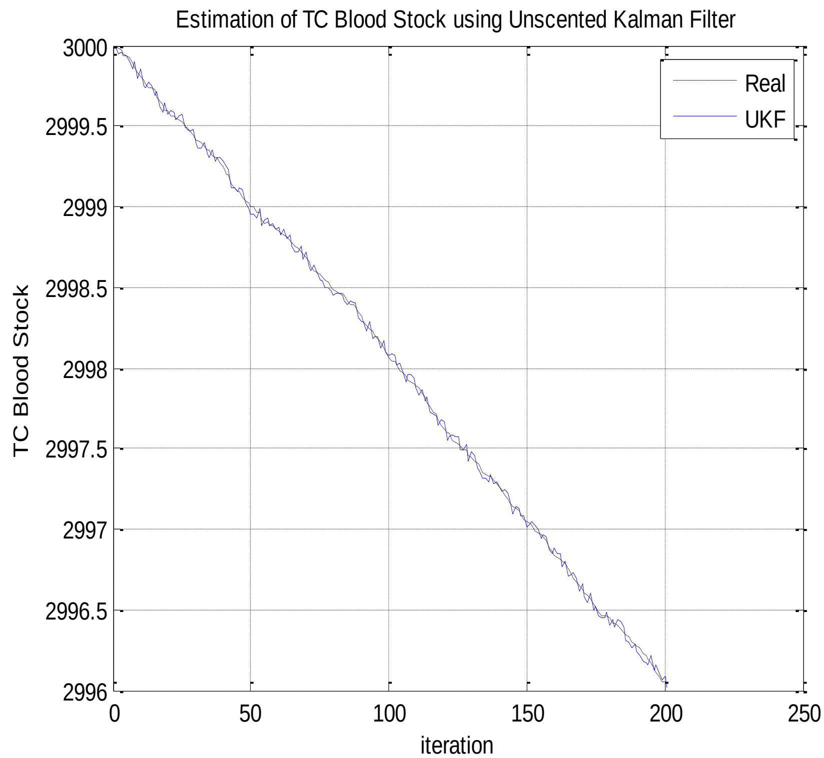

Figure 5. Estimation of TC blood using UKF methods with 200 iteration

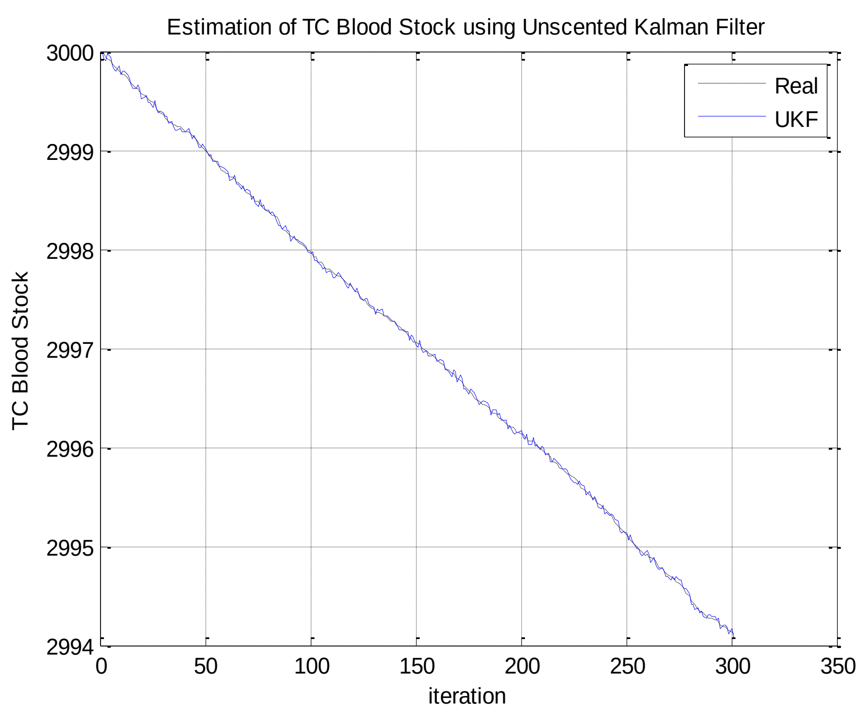

Figure 3. Estimation of TC blood using UKF methods with 300 iteration

Figures 1, 2 and 3 show that the estimation results of WB and TC blood stock have high accuracy with errors of less than 4% as we can see in the real graphs. The accuracy of Unscented Kalman Filter methods showed no significant difference. In Figure 1 and Table 2, it appears that the Unscented Kalman Filter method using 300 iteration with RMSE of 0.00321 has higher accuracy than that of 200 and 100 iteration with RMSE of 0.00407and 0.00491, but the difference is not much. Likewise, in Figures 2 and 3 with 200 and 300 iteration. In conclusion, UKF method can be used as a method estimating either WB blood stock or other blood types.

Table 2. Comparison of the RMSE values by the UKF based on 100, 200 and 300 iteration

	100 Iteration		**200 Iteration**		**300 Iteration**	
	WB	**TC**	**WB**	**TC**	**WB**	**TC**
RMSE	0.00381	0.00511	0.00307	0.00483	0.00221	0.00451
Simulation Time	6,189 s		8,256 s		10,371 s	

In general, the methods of Unscented Kalman Filter can be used as a method to estimate Whole Blood (WB) and Thrombocyte Concentrate (TC) blood stock with high accuracy. Based on the numeric simulation results above, it is likely that method can also be used to estimate other type of blood stock, so it can support the work of blood bank.

Conclusion

Based on the results of the simulation analysis and discussion, Unscented Kalman Filter (UKF) method can be used as a method to estimate WB blood stock with excellent accuracy and errors of less than 4%. Based on the simulation results above, it is likely that both methods can also be used to estimate othertype of blood stock, so it can support the work of blood bank management.

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