THE INCORPORATION OF ALGORITHM WITH NEWTON LAW OF COOLING AS A METHODOLOGY TO ESTIMATE THE TIME OF DEATH OF CORPSE OR CADAVER

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Abstract

Forensic science had been a large spectrum of science and technology for investigating or establishing facts in crime scene or civil law. It had been used widely to analyze and collecting evidences and help in recognizing process for any cases especially in crime cases. Its goal is to determine the fact and subsequently identify the truth. Beneath of all that, forensic science only work for truth by making sure the examination is complete, the test are perform correctly, the data is interpret deeply and the report is written correctly and easily understood by non-scientist. In fact, in forensic science one of the important things before undergo a deep investigation is to determine the time of death. Time of death is the time elapse since a person died. From the time of death, the time of dead person died can be obtain as well as suggest or get rid of suspects and strengthen or confute an alibi. The time of death determination introduced had been expanded and used in solving many cases in forensic investigation. Unfortunately, all methods now in use to determine the time of death are to a degree which is unreliable and not precise. They usually give vague or dubious answers. A method called Hensssgenomogram formula which based on Newton Law of Cooling had been introduced as the most versatile and gives accurate result. Therefore, a fully computerized algorithm will be made based on that method. The algorithm will also be support with decision making for analysis and comparison with other factor that also significant and contribute in estimating the time of death. Thus, any conflict that occurs within the result can be solved and concluded with a better result by providing a report along with analysis that had been made from the data provided through the investigation.

Keyword: algorithm, decision making, time of death.

1. Introduction

Nowadays, many countries had evolved and move towards better urbanization. Along with evolution of a country, there are also changes in the evolution of the citizens. Peoples who have high motivation and can adapt with the changes will have a better live along with the evolution of a country. However, for those who cannot adapt with the changes, they will find that life is hard and they are suffering with the urbanization. Consequently, for them to truly adapt with the urbanization change, many things can be done either bad or good things in order to obtaina great benefit from the urbanization changes.

words, crime is one of the options for people to adapt with the urbanization change. Furthermore, the changes of the urbanization had changed the crime rates. According to Lizotte (1982) the crime rates had changed because of the changes in industrial, social, and economic factors in the larger society. In addition, in Philippines, urbanization had been the major factor for the higher crime rates (Sanidad-Leones, 2006).

Therefore, in order to support analysis and assist crime investigation, forensic science had been introduced. Forensic science is an application of broad spectrum of science and technology that help in investigation or establish facts of interest in relation to crime investigation or civil law (DiMaio & DiMaio, 2001). In order words, forensic science is a legal way in investigating crime scene as the source of information or evidence resources for any crime that occurs. For any cases that happen, forensic science had been a bridge that connects the investigator to the attribute or things to find the source of the problem. It leads the investigator to find the clue, the proof, the suspect, the alibi, time of murder and so on.

Nowadays, the role of forensic science in the criminal justice arena is changing drastically. In the past, forensic science analysis often entered into the picture near the end of the criminal investigative process which is after the crime, after the investigation, after the arrest of a suspect, but before prosecution (Blagojevich & Trent, 2004). Currently, the forensic work often precedes an arrest. The changes of forensic science role substantially increase the significance of forensic science in the criminal investigative process. This is mainly due to the two factors: the increase awareness of forensic science and advances in technology (Stevens, 2012).

Due to the contribution of forensic science, the methods of the time of death determination had been introduced and had been used to solve many cases in forensic investigation. For example, forensic science contributes in estimating the time of death. It is because determination of the time of death is important in both criminal and civil cases. In criminal cases, it can set the time of the murder, eliminate or suggest suspects, confirm or disprove an alibi. In civil cases, the time of death might determine who inherits property or whether an insurance policy was in force. Unfortunately, all methods now in use to determine the time of death are to a degree unreliable and inaccurate (DiMaio & DiMaio, 2001). They usually give vague or dubious answers. The longer the postmortem interval, for example, the time between death and the attempt to determine time of death, the less precise the estimate of the interval. Thus, one of the ways for finding the better solution is through algorithm (DiMaio & DiMaio, 2001).

An algorithm is a sequence of unambiguous instructions for solving a problem for example for obtaining a required output for any legitimate input in a finite amount of time (Levitin, 2003). A computational algorithm is a deterministic step-by-step procedure to solve a computational problem. That is, the computational algorithm should produce a solution for any instance of the computational problem. The interest is to find an efficient algorithm, in terms of computing resources is to solve a given problem. Besides, an algorithm must be made through decision making so that the method used for estimating the time of death will become reliable and more accurate and come out with a better result.

Decision Support (DS) is a broad, generic term that encompasses all aspects related to supporting people in making decisions. The term DS that contains the word “support” refers to supporting people in making decisions. Thus, DS is concerned with human decision making (Bohanec, 2003). Decision Support System (DSS) is a class of information system (including but not limited to computerized system) that support business and organizational decision making. A DSS which design properly is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions (Ambarish, 1987).
On the other hand, DS needs certain portion that can assist DS in making more reliable decision. For the study on estimating the time of death, many factors that significant and related for estimating the time of death need to be including before a result could be produce. As decision making means helping to make a good decision, this study suggest that the algorithm along with its factor need to be combine and compare through decision making for producing a good and better result.

Thus, in order to find an efficient algorithm for time of death determination, this study embarks on the following objectives:

i. to design an algorithm for estimating the time of death.
ii. to implement an algorithms for estimating the time of death based on the condition of the cadaver.
iii. to evaluate the proposed algorithms in post-mortem interval for forensic analysis and statistical analysis in crime investigation.

The remainder of this paper is organized as follows. Section 2 discusses on the previous related works. The methodology adopted for this study is described in Section 3 and finally concluded with the conclusion in Section 4.

2. Previous Related Works

An algorithm is a representation of a solution to a problem. If a problem can be defined as a difference between a desired situation and the current situation in which one is, then a problem solution is a procedure, or method, for transforming the current situation to the desired one (Raymond, 2011).

As in criminal investigation, many cases need solves either in crimes, robbery, suicide and so on. All these cases must lead to a solution or decision in the end of the judgment. Therefore, cognitive strategies are normally defined in a way that clearly outlines the step-by-step process such as an algorithm that leads to a decision (Snook & Cullen, 2008).

There were a few approaches that express the algorithm approach where it practically used in decision making and in crime investigation fields as indicated in Table 1.

<table>
<thead>
<tr>
<th>Author</th>
<th>Methodology</th>
<th>Area in used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xu &amp; Chen (2003)</td>
<td>Shortest path algorithm</td>
<td>Criminal Networks</td>
</tr>
<tr>
<td>Chen et al. (2003)</td>
<td>Algorithm</td>
<td>Crime Data Mining</td>
</tr>
<tr>
<td>Keppens, Shen, &amp; Lee (2005)</td>
<td>Bayesian Network algorithm</td>
<td>Crime Investigation</td>
</tr>
<tr>
<td>Li, Kuo, &amp; Tsai (2010)</td>
<td>Rule extraction algorithm</td>
<td>Crime Prevention</td>
</tr>
<tr>
<td>Asante (2013)</td>
<td>Algorithm</td>
<td>Estimating the time of death</td>
</tr>
</tbody>
</table>
Table 1 shows that an algorithm had been used in variety of areas such as in criminal networks, crime data mining, crime investigation, crime prevention, future crime in crime data mining and estimating the time of death which acts as a process which helps in solving many crimes cases. This study is focuses on constructing an algorithm for the time of death determination. It seems that an approach of algorithm by Asante (2013) is the only methodology that focuses on time of death determination. Thus, this study will apply an algorithm introduced by Asante (2013). However, the algorithm still did not provide a good result since many factors were not considered in the time of death calculation. In addition, there was a system prototype that only functioning to calculate the algorithm without producing the report or anything related documents that could be a proof in helping the crime investigation. In spite of this, Asante (2013) highlighted that the automation of the algorithm could truly assist crime investigator in estimating the time of death. Accordingly, the present study attempts to develop a fully computerized algorithm of the time death estimation. While focusing on time of death determination methodology, primary task of medico-legal death time estimation is the reliable estimation of the time since death. Criminal investigations get most efficient if this period of time is communicated to the police already at the place where the corpse is found. Reliability as the most important principle can only be provided empirically by statistical analyses of mistakes of field studies. The standard of death time estimation in the early post-mortem period is determined by scientific contributions by German-speaking institutes of legal medicine. Methods of death time estimation based on cooling of the corpse show differences compared with other methods: The cooling of the corpse is mainly a physical process; the influence of biological processes such as fever ante-mortem, hypothermia or post-mortem heat production which is relatively low, physical conditions (anatomy) are recognizable and can be considered in death time estimation (Pounder, 1995).

The estimating the time of death is also known as post mortem interval or PMI. It acts as a medium that help a lot in crime investigation. From PMI, the time of death can be verified as well as neither suggesting nor eliminating the suspect and used for confirmation of an alibi. There are certain methods that have been used to calculate the time death estimation. In forensic science according to DiMaio & DiMaio (2001), there are many methods which related to the time of death determination. Two of the formulas that are the simplest to use are:

\[ \text{a. Time since death} = 37°C - \text{Rectal temperature (C)} + 3 \]  \hspace{1cm} (1)

\[ \text{b. Time since death} = \frac{98.6 \degree F - \text{Rectal Temperature (F)}}{1.5} \]  \hspace{1cm} (2)

Newton’s “Law of Cooling” was first published in 1701 in a paper entitled “ScalaGraduumCaloris” that appeared in the Philosophical Transactions of the Royal Society of London. A coroner uses a formula derived from Newton’s Law of Cooling, a general cooling principle, to calculate the elapsed time since a person has died. The formula is as follow:

\[ t = -10 \ln \left( \frac{T - Rt}{98.6 - Rt} \right) \]  \hspace{1cm} (3)

where \( T \) = the body’s measured temperature (°F)
\( Rt \) = the constant room temperature
\( T \) = elapsed time in hours since death

According to Roberts (2012), by using Newton’s Law of Cooling a more accurate estimate of the time of death could be found by taking two readings and averaging the two calculated times of death.
Pekka J. Karhunen (2007) has published five methods that had been used in estimating the time of death which is Henssge nomogram method, James and Knight method, triple-exponential method, Marshall method and rule of thumb methods. Those methods were recent methods that had been used in solving the time of death in crime investigation.

In Henssge nomogram methods, the time of death can be interpret in the semi-circle of body weight with the add of line drawn through the intersection of pre-set diagonal line of nomogram and line connecting of rectal temperature and ambient temperature. The effect of clothing, condition of water and air had been taken into consideration by empirical coefficient of correlation of body weight. The nomogram method can be described as the leading method of death time determination in the early post-mortem interval. The rectal temperature measurement is the only relevant type of measurement except for measurement of the central brain temperature (Pellini, 2011). It the equation that been used the most which takes account of temperature and body weight, ambient temperature, clothing worn and ventilation (J.Dix & M.Graham, 2000). The formula were as follows,

For ambient temperatures up to 23 °C

\[
\frac{T_{rectum} - T_{ambient}}{37.5 - T_{ambient}} = 1.25 \left( e^{Bt} \right) - 0.25 \left( e^{5Bt} \right)
\]  

(4)

For ambient temperatures below 23 °C

\[
\frac{T_{rectum} - T_{ambient}}{37.5 - T_{ambient}} = 1.11 \left( e^{Bt} \right) - 0.11 \left( e^{10Bt} \right)
\]  

(5)

Where the constant

\[ B = -1.2815 \text{ (kg}^{-0.625}) + 0.0284 \]

(6)

For triple-exponential method according to Louay M. Al-Alousi (2001), the time of death can be interpret through three formula that been used for each site and each group of related cases. The formula are average cooling formula, upper limit value formula and lower limit value formula. The average cooling formula is as follow:

\[
R_M = M_1 e^{M_{1tm}} + M_3 e^{M_{3tm}} + M_5 e^{M_{5tm}}
\]  

(7)

where \( M_1 \) to \( M_5 \) are the mean values of parameter,

\( R_M \) is the mean value of temperature different ratio, and

\( tm \) is the most probable postmortem interval (PMI) estimate

The upper limit value formula as follow:

\[
R_U = U_1 e^{U_{1tu}} + U_3 e^{U_{3tu}} + U_5 e^{U_{5tu}}
\]  

(8)

where \( U_1 \) to \( U_6 \) are the upper limit values of parameter,

\( R_U \) is the upper limit value of temperature different ratio, and

\( tu \) is the upper limit postmortem interval (PMI) estimate
The lower limit value formula as follow:

\[ R_L = L_1 e^{L_2 t_L} + L_3 e^{L_4 t_L} + L_5 e^{L_6 t_L} \]  

(9)

where \( L_1 \) to \( L_6 \) are the lower limit values of parameter, \( R_L \) is the lower limit value of temperature different ratio, and \( t_L \) is the lower limit postmortem interval (PMI) estimate.

The estimated time of death or postmortem interval then calculated by average cooling formula and range of time was calculated through upper and lower limit formula.

James and Knight method is a practical and much used simple method which take into account of environmental temperature by apply stepwise correction factors for the ambient temperature (James & Knight, 1965). The formula is as follow:

\[ T = (37^\circ C - T_{rect}) K_{env} \]  

(10)

where \( K_{env} \) are the coefficient that contain value of 1, 1.25, 1.5, 1.75 and 2 which to the environmental temperature of 0\(^\circ\)C, +5\(^\circ\)C, +10\(^\circ\)C, +15\(^\circ\)C and +20 \(^\circ\)C with the error limit approximately 2 hours if the time of death is 10 hours or less and error limit approximately 3 hours to 4 hours if the time of death is more than 10 hours.

Marshall method published an easily calculable modified mathematical formula based on Marshall and Hoare formula which is mathematically demanding and hardly applicable in casework. The method published is based on finding the time of body to cool to 85% of initial temperature different between rectal temperature and environmental temperature that depend on body size. The body cool to 85% of initial temperature different occurs in 19 hours for case of thin body, 28 hours for case of normal size body and 41 hours for case of fat body (Marshall & Hoare, 1962). To calculate the 85% of the initial temperature different, the formula is,

\[ T_{85\%} = 0.85 x (37^\circ C - T_{env}) \]  

(11)

where \( T_{85\%} \) is different between body temperature and environment temperature in the beginning of cooling process and \( T_{env} \) is the environmental temperature. The speed of cooling can be obtain through formula of

\[ S_{thin} = T_{85\%} / 19h \]  

(12)

and time of death can be calculated through a formula as follow:

\[ T = (37^\circ C - T_{rect}) / S_{thin} \]  

(13)

For rule of thumb, it is recommended not to be used for case work although it had been used more in practice for estimating the time of death for patient that died due to natural causes. This is because the method cannot take account or describe for any confusing variable (Henssge, Knight, Krompecher, Madea, & L.D.Nokes, 2002). There are two methods to calculate the time of death as shown below,
If the temperature using a Farenheit degree,

\[
\text{Time of death} = \frac{(T_{\text{rect0}} - T_{\text{rect}})}{1.5}
\]  

(14)

And if the temperature using a Celcius degree,

\[
\text{Time of death} = (T_{\text{rect0}} - T_{\text{rect}}) + 3 \text{ hours}
\]  

(15)

Where \( T_{\text{rect0}} \) is the initial temperature  
\( T_{\text{rect}} \) is rectal temperature

Based on five methods tested by Pekka (2007) for estimating the time of death, it had been found that Henssge nomogram method with its correction factor was the most versatile and gave the most precise results in homicide and accidental drowning cases (Pekka J. Karhunen, 2007). According to L. Carl Leinbach (2010), Henssge nomogram method is based on Marshall and Hoare equation where the basic comes from Newton Law of Cooling method. Asante (2013) had developed an application based on Newton Law of Cooling as it is consider as the very basic formula in estimating the time of death. Therefore, due to the reason of Henssge nomogram and its correction factors, this study will adopt the algorithm proposed by Asante (2013) as the main component and will improve that algorithm with Henssge nomogram correction factors in order to produce a better result for the time of death estimation.

Moreover, variables such as posture of body, site of reading of postmortem body temperature, emaciation and micro-environment such as rain, humidity, air and so forth were not taken into account in the Asante (2013) study for determining the time of death. Hence, in response to this issue, this study will consider the variables such as time of cadaver or corpse found, rectum temperature, room temperature, mass of cadaver or corpse, condition of body of corpse or cadaver, condition of clothes of corpse or cadaver, layer of the clothes, condition of air and condition of water that could improve the current model to account for long post mortem period and accurately estimate time of death which can be used for scientific crime investigation.

3. Research Methodology

In the beginning, a nomogram is a diagram which representing the relations between three or more variables quantities by means of a number of scales. In fact, it can set up the value of one variable that can be found by a simple geometrical construction such as by drawing a straight line intersecting the other scales at the appropriate values (Timashov, 2013). It had been applied in estimating the time of death in crime investigation which called Henssge nomogram. Henssge nomogram is a diagram which based upon a formula which approximate the sigmoid shaped cooling curve. Henssge nomogram method was according to Newton Law of Cooling Method which taken temperature as its main component in estimating the time of death (Asante, 2013).

Henssge nomogram method had been divide into two nomogram which is above 23°C and below 23°C. Figure 1 shows the example on how it is used. Through the obtain by the oblique line, a line is drawn and taking weight into consideration which then, the time of death is expresses in hours.
Currently, Asante (2013) has developed an application to estimate time death based on Newton Law of Cooling method which is the base of Henssge nomogram method and Marshall and Hoare method. This study will improved Asante (2013) work. In addition, this study will combine corrective factors from Henssge nomogram method which include all the variables such as time of cadaver or corpse found, rectum temperature, room temperature, mass of cadaver or corpse, condition of body of corpse or cadaver, condition of clothes of corpse or cadaver, layer of the clothes, condition of air and condition of water. Asante (2013) works need to be improved as the variables such as posture of the body, site of reading of the postmortem body temperature, emaciation and micro-environment such as rain or humidity or any other variables that were not considered for the determination of the time of death. Meanwhile, to improve the current model, all of the variables stated in the previous sentence could be taken into account. The corrective factors need to be combine with Asante (2013) works as Henssge nomogram method with its correction factor was the most versatile and gave the most precise results in homicide and accidental drowning cases (Pekka J. Karhunen, 2007). Thus, this study is aimed to help improving the time of death application in order to improve the result in estimating the time of death for crime investigation. Figure 2 illustrates the flow that will be followed to determine the time of death.

Figure 2: Architecture of algorithm for estimating the time of death

Criteria conduct in this study
- Time of cadaver or corpse found
- Rectum temperature
- Room temperature
- Mass of cadaver or corpse
- Condition of body
- Condition of clothes
- Layer of clothes
- Condition of air
- Condition of water

Figure 1: Henssge nomogram above 23 °C
From Figure 2, it can be seen that the algorithm is based on criteria provided from the crime scene which are time of cadaver or corpse found, rectum temperature, room temperature, mass of cadaver or corpse, condition of corpse or cadaver body, condition of clothes of the corpse or cadaver, layer of the clothes, condition of air and condition of water. Next, all of the criteria provided will insert into Graphical User Interface (GUI) System based on the time of death algorithm that been developed. Then, the data that had been input into the algorithm will be analyzed to predict the time of death. Finally, the estimation of time of death will be stored in the database and will produce the reports. The algorithm for estimating the time of death algorithm proposed by this study is shown in Figure 3.
Figure 3: The proposed algorithm for estimating the time of death

1. Start
   - Set initial temp = 37.2
   - Initialize t = 0.001

2. If condition clothed, p=0.3
   - If condition naked, p=0.4

3. Input rectum temperature, T
   - Input ambient temperature, Ta

4. Refer Table 2

5. Set diff = T x 0.001

6. BSA = 0.1173 x (weight ^ 0.6466)
   - SF = 0.8 x BSA x (10000/weight)
   - K = 0.0006125 x SF – 0.05375

7. X-axis = Ta + (37.2 - Ta) x e^(-kt)
   - Y-axis = 0.1173 x (weight ^ 0.6466)
   - Total = X-axis + Y-axis

8. If (T-Total) < = diff

9. t = t + 0.001

10. Time of death = t

end
The algorithm will be compared with the corrective factor of Henssge nomogram method as shown on Table 2 and will be evaluated based on its performance and results. The result of the time of death will be assessed by domain experts in computer science and forensic science in terms of its functionality, usability towards utilizing computer science and information technology in crime investigation. It will also include the analysis and documentation which will be delivered through report. Thus, it will provide detail information of death estimation time and analysis outcome.

Table 2: Corrective Factor of Henssge nomogram method

<table>
<thead>
<tr>
<th>Dry clothing / Covering</th>
<th>In air</th>
<th>Corrective Factors</th>
<th>Wet through clothing/ covering wet body surface</th>
<th>In air</th>
<th>In water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.35</td>
<td>naked</td>
<td>flowing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.50</td>
<td>naked</td>
<td>still</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.70</td>
<td>naked</td>
<td>moving</td>
<td></td>
</tr>
<tr>
<td>naked</td>
<td>moving</td>
<td>0.75</td>
<td>1-2 thin layer</td>
<td>moving</td>
<td></td>
</tr>
<tr>
<td>1-2 thin layer</td>
<td>moving</td>
<td>0.90</td>
<td>2 or more thicker</td>
<td>still</td>
<td></td>
</tr>
<tr>
<td>naked</td>
<td>still</td>
<td>1.00</td>
<td>2 thicker layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 thin layer</td>
<td>still</td>
<td>1.10</td>
<td>2 thicker layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3 thin layer</td>
<td>moving or still</td>
<td>1.20</td>
<td>More than 2 thicker layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 thick layer</td>
<td>moving or still</td>
<td>1.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-4 thin layer</td>
<td>moving or still</td>
<td>1.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>more thin/thick layer</td>
<td>moving or still</td>
<td>1.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thick bedspread</td>
<td>moving or still</td>
<td>1.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thick bedspread and clothing combine</td>
<td>moving or still</td>
<td>2.40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Conclusions

Estimating the time of death is a significant task for both criminal and civil cases. Estimating the time of death can specify the time of the murder, extinguish or propose suspects, affirm or reject an alibi. In civil cases, the time of death might determine who inherits property or whether an insurance policy was in force. As discussed earlier, estimating the time of death has a great assist in crime investigation. Therefore, a reliable result from the time of death estimation should be significant because it will connect with the crime or civil cases. To produce a reliable result, all the data that had been gathering either from the cadaver or corpses must be made into conclusion. Thus, in information technology era, a combination of decision making and algorithm could assist to produce more reliable and accurate time of death estimation.
References


