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CAMERA-BASED TODDLER FALL DETECTION SYSTEM BY USING KALMAN FILTER

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ABSTRACT

Monitoring a toddler is a tedious job, yet a very important one. Fall down is the most common risk that leads to injury during the process of learning to walk. Thus, this paper proposed an algorithm to detect automatically the event of toddler fall down to assist the supervision process by alerting the caretaker if necessary. This system comprises of a background subtraction module to detect region of interest, a tracking module using Kalman filter to track toddler movement and a decision module through decision tree process to determine the toddler state. System performance is evaluated based on three metrics, which are accuracy, sensitivity and specificity. The proposed algorithm works well with a low error performance. Further research should be done to improve the robustness of the system for real life environment implementation.

Keywords: *Fall Down, Toddler Monitoring, Kalman Filter, Decision Tree Process and Background Subtraction Module*

1. INTRODUCTION

Toddler falls under category of children between 1 to 3 years old [1]. Usually, toddler is the phase where human learns to walk, climb, running and speaking. These activities are the most crucial and significant processes for a healthy growth of toddler. Intuitively, parents will try their best to protect their children and ensure their safety. However, toddler always expose to danger that leads to unintentional injuries, especially fall down because of walk and climb learning process. Study on Center for Disease Control and Prevention (CDC) Childhood injury revealed that fall was the leading cause for the injury among toddler [2]. Therefore, toddler fall detection system is an essential technology for homecare system that can act as a surveillance tool to assist parents' supervision.

In general, toddler cannot realize any danger surrounding them during playing or walking activities. So, parents do not have any other choice but to always supervise and stay closed to them. Yet, it is almost impossible to stay closed to them for 24 hours a day. Parents may leave their toddlers to play by themselves since they need to attend other personal issues. Thus, an automatic toddler fall detection system can be implemented to assist the parents in monitoring and predicting any fall down event.

Previous researches normally focus on elderly people fall detection due to the market demand of monitoring people older than 60 years old. Most of the systems used sensors such as accelerometers or help buttons that are easily reachable by the elderly to assist them during in a case of fall event. A comprehensive survey on sudden fall event can be found in [3]. But, these methods is not suitable for toddlers since they are more active compared to elderly and they might remove the sensor due to comfort issue. Besides that, toddler still cannot fully utilize the help button if they face any injury after the fall down. Thus, we suggest to use a Red, Green, and Blue (RGB) camera as the sensor to capture the whole scene, so that it can be used to predict and detect the movement of the toddler. The camera will be mounted on a stable and suitable place to minimize any occlusion issue.

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Table 1: Previous Work Comparison On Toddler Surveillance System

	Method				
	[4] Yang, M.-T. et al. 2013	[5] Na, H. et al. 2011	[6] Hiroyuki Kakara et al. 2013	[7] Nomori, K. et al. 2009	[8] T. V. Spina et al. 2013
Hardware	Kinect	Color Camera	Acceleration-gyro sensor + Color camera	Color camera	Color camera
Detection Stage	Early-warning	Track off floor	Fall	Behavior modelling	Behavior modelling + video segmentation
Targets	Toddler	Toddler	Toddler	Infant	Toddler
Algorithm	Skeleton + SVM + Floor	Optical flow	Angular velocity + Probability map	Bayesian Network	Fuzzy Object Model (Cloud System Model)

2. LITERATURE REVIEW

There are various method and application that have been implemented and proposed for detecting toddler movement, especially for fall reaction. Table 1 lists down some previous works on the related topic.

From Table 1, it can be seen that various sensor have been used to detect the toddler action, such as Kinect camera, color camera and combination of acceleration-gyro sensor with color camera. It shows that the toddler fall detection and behavior analysis are still in early phase and can be improved by further research. Selection for which hardware is the best for research is uncertified but can be narrow down depending on budget and specification. Most of the researches prefer to use color camera as it is the most commonly available hardware in the market and cheaper. The combination of acceleration-gyro sensor with color camera can increase the accuracy of system. However, it is obstructive to the toddler movement, which makes them uncomfortable. Some papers [4, 5] suggested that alert or alarm signal should be sent before the fall incident happened, whereas others prefer the detection is identified after the incident has occurred. Early warning seems to be the better choice but reliability and consistency of the system will be the main issue. It needs to consider many possibilities of modules and action that may lead to fall, which in turn will slow down the system response in real life implementation.

Previous works reported that most of their systems have their own tracking tools due to uncertainty in background subtraction result because of various conditions. However, it can be improved in the future by using robust foreground extraction method in [9]. By adding a tracker module, the error rate will can be reduced and a prediction can be done to improve the system performance. Normally, Kalman filter [10] and particle filter [11] are the common tracking tool to be used in image processing. Kalman filter normally deal with the linear model while the particle filter deal with the nonlinear model. Some researchers used Markov random walk filtering [12] for nonlinear model. The fall down detection can be assumed as a linear model behavior since it involves an action of normal walking that follows the linear system rule. Therefore, we suggest that the Kalman filter for the toddler surveillance tracking tool to minimize the error in detection process.

For the decision making part, we can observe different kind of methods had been applied to solve the problem such as support vector machine (SVM) [13], Hidden Markov Model (HMM) [14], Decision binary tree [15] and combination of any former methods [16]. Our system considers two types of action which are fall and non-fall action. Thus, binary decision tree is proposed for the system as it consumes low computational resource as compared to other methods.

3. METHODOLOGY

This paper proposes a toddler surveillance system that consists of three main modules, which are detection, tracking and decision making. Detection module allows the system to select and initialize a suitable target while tracking enables the system to track the region of interest. In the final module, the decision making process allows the system to decide the current state of the toddler. The block diagram of the overall system is shown in Fig. 1.

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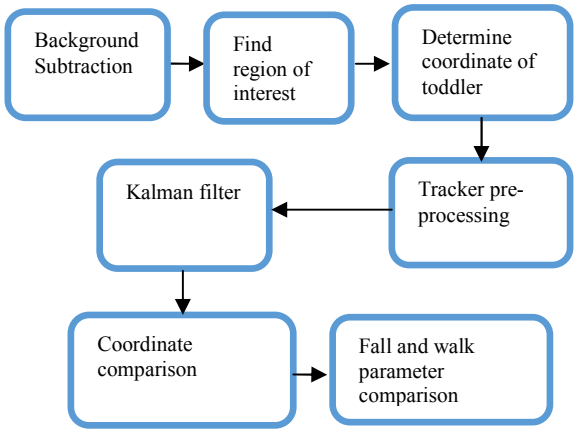

Figure 1: Block Diagram of the Toddler Fall Detection System

3.1 Detection

Detection process plays the main role in determining the overall system performance as it will determine how far the observation fares to the actual situation. Therefore, a good background subtraction method is needed to develop a good system. Modified background subtraction codebook modelling is implemented in which the update is based on texture background and color background modellings [17, 18]. Textured background model makes up the main structure of background subtraction module while color background modelling is used to refine the false negative output from texture background model. In overall, background subtraction module is updated based on the conventional codebook model. A bounding box is then drawn surrounding the toddler image and coordinates are used for tracking purpose.

3.2 Tracking

A system that relies on detection process only is not reliable, especially in dealing with actual situation. Sometimes, there is no detected object in certain situations such as during sudden change of illumination or sudden sprint in the toddler movement. Thus, a tracking module is introduced to reduce the error when the background subtraction method fails to detect any foreground. A set of 5 previous coordinates of the toddler's bounding box, which is obtained from the detection module will be saved and evaluated by analyzing their distance standard deviation. If the values are within an acceptable range, the detected foreground region of interest will be conformed as a true track and hence, normal tracking process will resume. In this paper, we proposes Kalman filter as the tracker since it is able to deal with various challenges and surrounding in toddler monitoring. It consists of two main components, which are a time update equation (predictor) and a measurement update equation (corrector). The predictor will project (in time) the current state and error covariance to obtain a priori estimation for the future step. On the other hand, corrector combines and merges recent measurement with priori estimation to obtain an improved posteriori estimation [19]. Here, we will use the corrector value to evaluate our system in the decision making process. Equation 1 shows the Kalman filter main equation:

$$\widehat{X_k} = K_k * Z_k + (1 - K_k) * \widehat{X_{k-1}} \quad (1)$$

where $\widehat{X_k}$ is the current estimation (current estimated toddler coordinate), K_k is the Kalman filter gain, Z_k is the measured value (background subtraction obtained value) and $\widehat{X_{k-1}}$ is the previous estimation.

3.3 Decision Making

The decision making module is to evaluate whether the observed toddler is playing normally or on the brink of falling down. As stated before, a value obtained from the corrector of the Kalman filter that does not vary much from the actual situation is more suitable as compared to the coordinate obtained from background subtraction method. All values provided by the Kalman filter corrector will be stored and evaluated. The difference between the y-coordinates of toddler's bounding box at the current state and the previous state is used to decide either the state should be stored or not. If the difference is larger than +6, the state will be stored as a falling parameter while if the value is within the steady state range, which is between -6 and +6, the state will be stored as a walking parameter. However, if the state value is not within these two ranges, the toddler might be doing other activities such as climbing, but this action does not cover in our proposed system. Then, the system will be compared against both the fall and walk parameters. If fall parameter is larger than walk parameter, the system will mark the toddler state as fall or vice versa.

4. RESULTS AND DISCUSSION

A total of 23 videos have been tested to analyze the proposed system. The input videos are classified into three categories, which are a toddler with forward fall, a toddler with backward fall and a toddler who just walks around. This system was

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coded in C++ language using Microsoft Visual Studio C++ 2010 Express platform with OpenCV 2.4.9 library. This paper only considers two types of fall, which are forward and backward fall. In addition, the camera is positioned to take videos from the side view. During the data collection, the toddler was protected where all fall incidents happened on a thick carpet or blanket with his mother supervision.

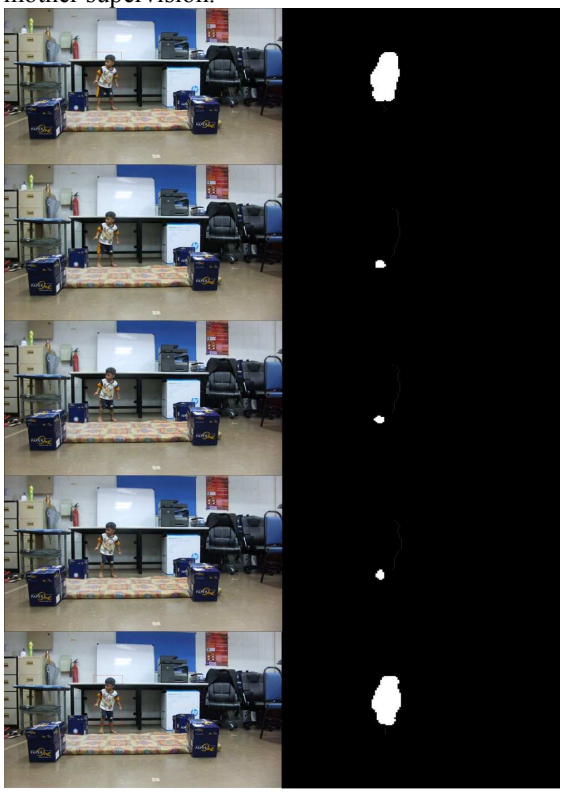

Figure 2: Tracking the Toddler Movement When No Foreground Is Detected

Fig. 2 shows that the Kalman filter is essential for the system. Only the first and the last frames have detected foregrounds and not in the middle frames. However, Kalman filter has been used to predict and track the toddler movement where the red and blue cross marks are the predictor and corrector coordinates, respectively. It worked very well in tracking the toddler so that its trajectory can be used to detect any abnormality.

Fig. 3 show the pattern change in the toddler movement when a sudden fall happened. Based on Fig. 3, toddler image will appear to be smaller as it is the normal reaction to protect himself from any injury even though he knows in advance that he will not get hurt falling on a thick carpet. The consistency in both detection and tracking modules has contributed to the successful implementation of the decision making process.

Performance of the proposed system is evaluated using three main performance metrics that are accuracy, specificity and sensitivity. All videos are consisted of a series of frames with a toddler who falls down, which will be marked as positive sample (P) while the rest will be marked as negative sample (N). The true positive (TP) is defined as the number of system that accurately detects the toddler's fall action in positive samples, while false positive (FP) is defined as the number of system that accurately detects toddler's fall action in negative samples. On the other hand, true negative (TN) is defined as the number of system correctly detects toddler as no fall action in negative samples and false negative (FN) is defined as number of system detects toddler as no fall action in positive samples.

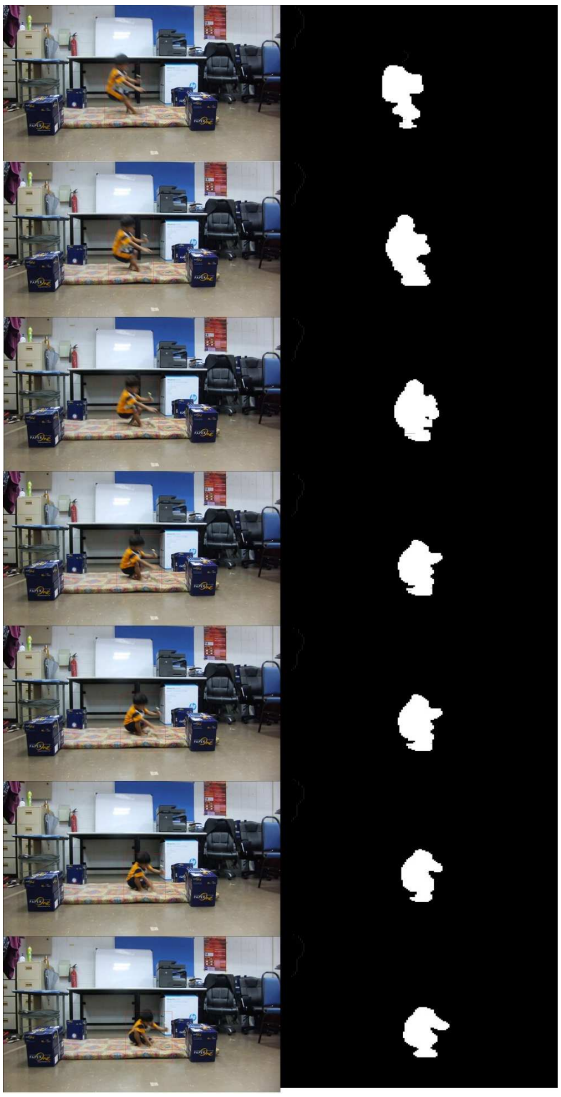

Figure 3: The Pattern Change for Toddler Fall Down Moment

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$$Accuracy = \frac{TP+TN}{P+N} \quad (2)$$

$$Specificity\ (True\ Negative\ Rate) = \frac{TN}{FP+TN} \quad (3)$$

$$Sensitivity\ (True\ Positive\ Rate) = \frac{TP}{TP+FN} \quad (4)$$

Table 2: Simulation Result

Accuracy(ACC)	Specificity(SPC)	Sensitivity(TPR)
0.7826	0.7778	0.8462

The average accuracy obtained by the system is 78.26%, which shows good system capability in that it capable of detecting and tracking the toddler movement correctly. The decisions made are also true in most of the cases, where fall and walk actions are identified accurately. In addition, the high sensitivity of the system proved that it is suitable for real situation implementation, even though toddler action is unpredictable. Thus, a high sensitivity system is needed so that the system is more robust. The specificity performance of the system is 77.78% where it has managed to correctly reject the samples for most of the time, even when the focus is on toddler fall reaction. For both fall types, forward and backward cases, the former case managed to achieve 6 TP cases out of from 8 cases, while the latter case obtained 5 TP cases out of from 6 cases. Hence, the system proved to be able to handle both types of fall under various background subtraction inaccuracies, which is supported by tracking module.

However, the system is built for a single toddler at one time, which limits its usage in real life implementation. This is because toddlers tend to play with friends in which will increase the difficulty in extracting foreground regions. Hence, future work should consider a system with capability of monitoring more than one toddler at one time. Furthermore, multiple hypothesis tracker [20] can be implemented to solve the challenge of more than one toddler surveillance. Besides, multiple-camera system will also enhance the proposed system, where a various view of the toddler can be extracted to make a better decision and overcome occlusion issue.

5. CONCLUSION

In conclusion, a novel algorithm to detect toddler fall event has been successfully built to assist parents' supervision. The algorithm is useful in helping parents to observe their toddler by detecting the abnormalities and alerting the caretaker. Based on the simulation results, the algorithm has managed to obtain low error value, with accuracy, specificity and sensitivity of 78.26%, 77.78% and 84.62%, respectively. The proposed system focuses solely on single toddler monitoring from a single view camera. Thus, further research will be done to improve the system performance to cater multiple toddlers in a scene and videos captured using multiple cameras.

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