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RESEARCH ARTICLE

PROTECTION OF A SINGLE QUBIT QUANTUM STATE FROM DECOHERENCE.

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Abstract

When a quantum system interacts with the environment its superposition or coherence can be lost. Thus there will be decoherence. Decoherence causes loss of information. For effective information processing the quantum states should be protected from decoherence. We employ weak measurement and measurement reversal to reduce decoherence in a single qubit quantum state interacting with the environmental noise due to amplitude damping. To study the variation in decoherence, the trace distance is investigated. The trace distances for different weak measurement strength 'm', and decoherence magnitude 'D' are calculated. It is seen that through weak measurement and measurement reversal, decoherence in the system can be reduced considerably.

Introduction:-

The power of quantum information theory comes from the fact that quantum states can exist in superposition. But when a quantum system interacts with the environment its superposition can be lost (David McMahon,2008). This results in decoherence - loss of coherence. For effective quantum information processing the quantum states should be protected from decoherence.

We employ a novel idea (Shu-Chao Wang, et al 2014) of weak measurement and measurement reversal for protecting the quantum states from decoherence. Any quantum mechanical measurement will disturb the system irrevocably. But when weak measurement is used the interaction between the measuring apparatus and observed system or particle is weak. Hence the disturbance caused by weak measurement is less compared to strong measurement. The disturbance can be further reduced by measurement reversal.

Throughout the work we use trace distance as a measure of decoherence (Manju Bhatt,et al.,2014). When decoherence increases the trace distance increases. Trace distance (David McMahon,2008) is calculated as $\sqrt{1-<\psi|\rho|\psi>}$, where ρ is the density matrix and $|\psi> = \alpha|0> +\beta|1>$ and $\alpha^2+\beta^2$ =1 or $\beta^2 = 1-\alpha^2$.

Application of weak measurement to a single qubit in pure state:-

We consider a single qubit quantum system in pure state whose density matrix can be written as

$$\rho(0) = \begin{bmatrix} \alpha^2 & \alpha\beta \\ \alpha\beta & \beta^2 \end{bmatrix} \qquad (1)$$

Weak measurement operator (Yong-Su Kim,et al.,2009), $M_2 = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{1-m} \end{bmatrix}$ is then applied to the above system. Here 'm' is the weak measurement strength. The trace distance of the outcome $\rho = M_2\,\rho(0)$

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is $$\sqrt{(1-\alpha^2)(1-\sqrt{1-m}\,)} \qquad (2)$$

Interaction of the system with the environment:-

This system, after weak measurement is allowed to interact with the environment. A type of noise due to this environmental interaction can be modelled using the following amplitude damping channel (M. A. Nielsen,et al.,2000).

$$\rho_W = \varepsilon_{AD(\rho)} = \sum_{i=0}^{1} E_i\ \rho\ E_i^{\ +} \qquad (3)$$

with , $E_0 = \begin{bmatrix} 1 & 0 \\ 0 & \sqrt{1-D} \end{bmatrix}$, $E_1 = \begin{bmatrix} 0 & \sqrt{D} \\ 0 & 0 \end{bmatrix}$.

Here 'D' is the magnitude of decoherence(M. A. Nielsen,et al.,2000) . The trace distance is $\sqrt{1 - <\psi|\rho_W|\psi>}$ and is evaluated as

$$\sqrt{1-\{\alpha^4+\alpha^2\beta^2 D\sqrt{1-m}+\alpha^2\beta^2\sqrt{1-D}+\alpha^2\beta^2\sqrt{1-D}\sqrt{1-m}+\beta^4(1-D)\sqrt{1-m}\,\}} \qquad (4)$$

Application of measurement reversal to the decohered qubit:-

Then we apply measurement reversal operator (Yong-Su Kim,et al.,2009) $M_R = \frac{1}{\sqrt{1-m_r}}\begin{bmatrix} \sqrt{1-m_r} & 0 \\ 0 & 1 \end{bmatrix}$ with measurement reversal strength $m_r = m + (1-m)D$ to the above decohered qubit. The corresponding density matrix is $\rho_{MR} = M_R \rho_W$. We again evaluate the trace distance $\sqrt{1 - <\psi|\rho_{MR}|\psi>}$ as

$$\sqrt{(1-\alpha^2)\{\,1-\alpha^2 D\sqrt{1-m}-\sqrt{1-D}\,\}} \qquad (5)$$

Result and Discussion:-

When weak measurement is applied to a qubit in pure state, the decoherence of the system increases. The variation in decoherence with weak measurement strength is studied by calculating the trace distance. Fig.1 shows how the trace distance varies with different α(alpha) and m values. It is clear that when the value of α increases the trace distance decreases. So for better results we consider $\alpha > \beta$,that is $\alpha > \sqrt{1-\alpha^2}$. For further calculation we choose $\alpha = 0.8$.

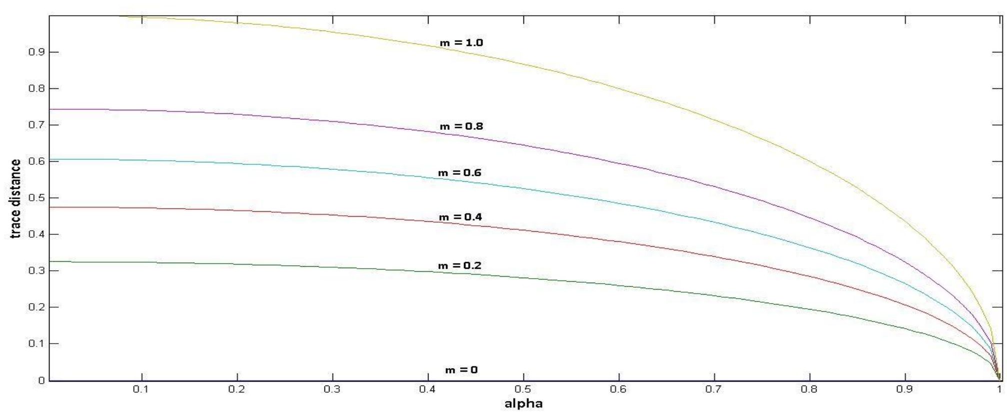

Fig.1:- Variation of trace distance when weak measurement is applied to a single qubit.

Trace distance variation for different values of weak measurement strength m and decoherence strength is plotted in Fig.2. Trace distance increases with m and D values.

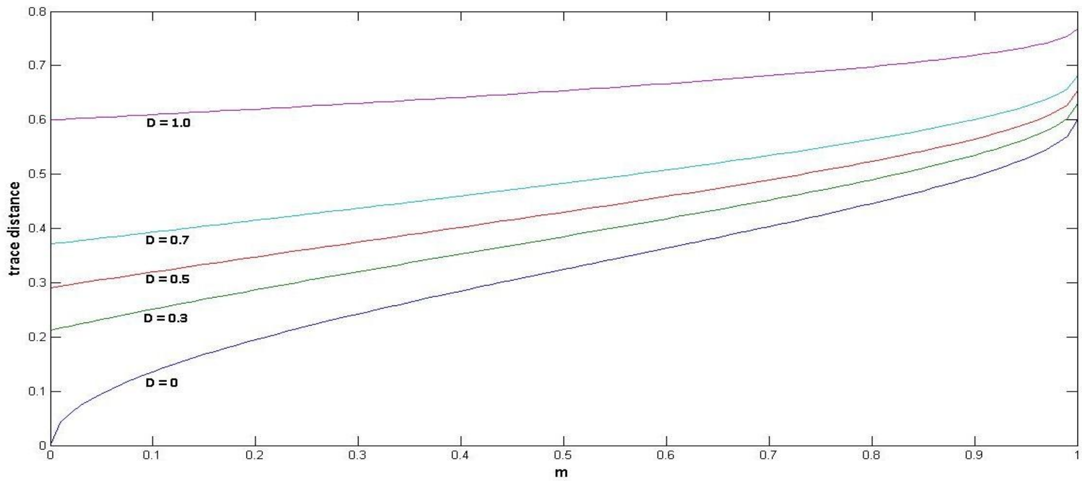

Fig.2:- Variation of trace distance when the qubit interacts with the environment.

When measurement reversal is applied, trace distance increases with measurement strength m and decoherence strength D. (Fig.3)

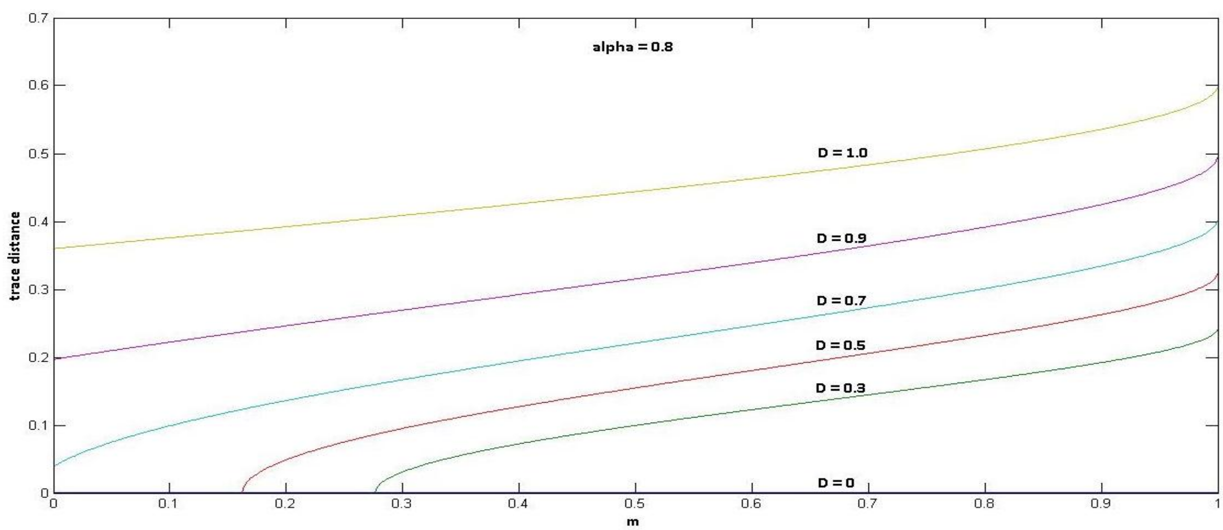

Fig.3:- Variation of trace distance when measurement reversal is applied

Trace distance due to weak measurement is compared with that due to measurement reversal. It is clear that using measurement reversal we can reduce the trace distance and thereby decoherence considerably for a single qubit quantum state. The difference in the trace distances for D = 0.5 is as shown in Fig.4.

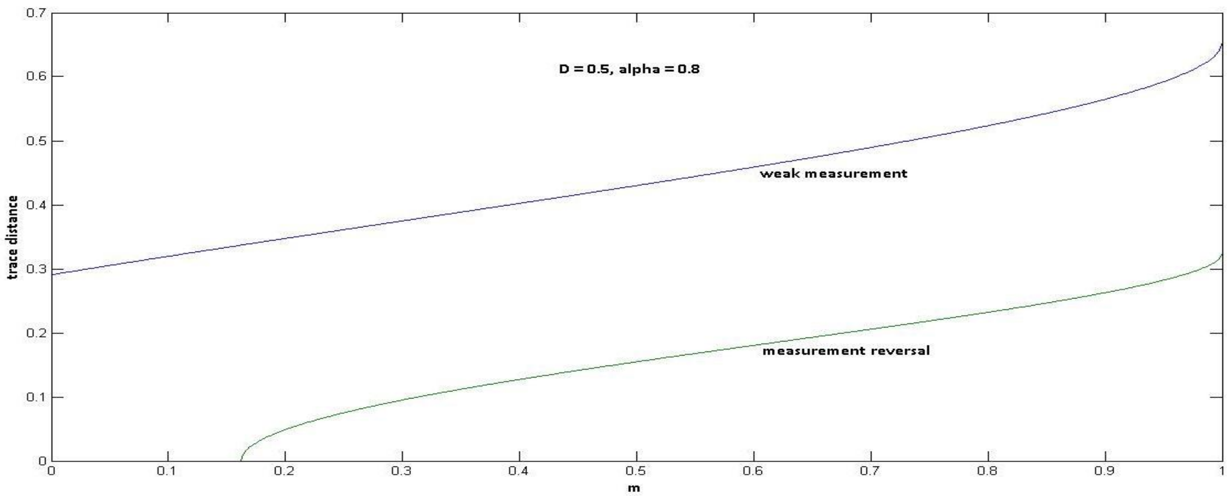

Fig. 4: -Comparison of trace distance due to weak measurement and measurement reversal

Conclusion:-

Weak measurement and measurement reversal have been practically realised in many physical systems. These are powerful tools to achieve approximate noiseless amplification. From our work it clear that measurement reversal can reduce decoherence due to amplitude damping in a single qubit quantum state considerably. We hope our work can also contribute to the world of quantum information and processing.

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